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EXPERIMENTS IN THE BIOLOGY AND ECOLOGY OF SPECIES OF THE GENUS *TRICHOGRAMMA* WESTW. AND THEIR USE IN PLANT PROTECTION*

The experiments presented in this paper are concerned with *Trichogramma evanescens* Westw., *T. cacoeciae* March., and *T. embryophagum* (Htg.) (*Hymenoptera, Chalcidoidea, Trichogrammatidae*). It was found that 7 generations of *T. evanescens* and *T. cacoeciae* and 6 *T. embryophagum* generations can develop yearly in central Poland. The species most resistant to low temperatures are *T. embryophagum* and *T. evanescens*, while *T. cacoeciae* is the least resistant species. The results of experiments pertaining to the dispersal and activity of *Trichogramma* in relation to the density of the host population are given. Distinct differences were found between the species as concerns vertical dispersal, the effect of the parasite population density on the offspring of the parasite and host, as well as the degree to which it is polyphagous. The results of experiments in the control of pests through the introduction of laboratory reared *Trichogramma* are also presented.

Contents

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I. INTRODUCTION

1. Problems and aim of work

Trichogramma, as one of the most effective parasites of the eggs of harmful insects, has enjoyed a continuous interest among adherents of the biological control of insect pests for over fifty years.

And yet, today, the whole series of problems in the fields of biology, ecology, practical use in the biological control of plant pests, and even the taxonomy of *Trichogramma* has not been sufficiently worked out. One cause of this, among other things, has been the lack of distinctive morphological differences between individual species, as well as changes in the natural population of *Trichogramma*, connected (in the majority of the cases) with complicated relations in the field of parasite-host relationships.

So far, no experiments using a uniform method have been conducted with all or even a few species of *Trichogramma*. In most instances, papers concern only one species, or frequently consider several species together as one, e.g., *Trichogramma evanescens* Westw.

Taking into consideration the extent of our knowledge of *Trichogramma*, as well as the present requirements of plant protection, some problems from the fields of biology and ecology, connected with several species of this parasite: have been set up as the purpose of this paper, namely:

a. The number of generations and the sum of the effective temperatures in different varieties;

b. The effect of low temperatures on activity;

c. Dispersion and the influence of the density of the hosts' egg deposits on dispersion;

d. The influence of the density of population of *Trichogramma* on the offspring of the parasite and host;

e. The classification of the hosts of *Trichogramma*

During the experiments, an attempt was made to hold similar testing conditions for each species tested. The investigations over changes in numbers were not completed, so that only elementary results of these experiments pertaining to *T. cacoeciae* March, in the orchard are given. Thorough discussion has been given on the basis of procured material, of particular questions which are certain to be of much value in the use of *Trichogramma* in the control of plant pests; e.g., the influence of increased density of the host population on the dispersion of *Trichogramma,* changes in numbers of *Trichogramma* in the orchard, and the effect of low temperatures on its activity.

Because of the limited knowledge in the field of taxonomy of *Trichogramma* and the resultant possibilities of misunderstanding, it is necessary to be familiar with the latest works on this subject. A critical analysis of these papers along with the results of our own tests, allows to form our own view of this kind of taxonomy at least about the species which were the subject of the present experiments and which are encountered in Poland. In order to avoid misunderstandings, a brief description of these species has been included.

Simultaneously with the experiments on biology and ecology, experiments were run on the destruction of pests, of vegetables, fruit trees, and forest through the introduction of laboratory grown parasites. Tests of this type are well represented in the world's scientific literature, but only in recent years have they awakened particular interest in Poland.

The tests were conducted from 1957 to 1962 in several locations, but mainly in orchards and vegetable fields on the Łomna farm near Warsaw. Several methods of experimentation were used, depending on the problems involved; therefore, each method has been presented in the part of this study to which it pertains.

2. Taxonomical relations in the *Trichogramma* genus

The taxonomy of *Trichogramma* Westwood 1833 (*Hymenoptera, Chalcidoidea, Trichogrammatidae*) has not yet been completely settled. In recent years several publications have appeared (Quednau 1956,1960, Telenga 1959a, Flanders and Quednau 1960) which, on the base of morphological, anatomical, biological, and ecological differences tried to settle the taxonomy of *Trichogramma* genus.

In 1956 Quednau revised the former systematics of the Western European species, reducing all species which had been described to that time to four: *T. evanescens* Westw., *T. cacoeciae* March., *T. embryophagum* Htg., and *T. semblidis* Aur. Besides the differences resulting from the parasite-host relationships, he also gives morphological differences between the species. Quednau's criteria of division, based on the differences in the construction of the antennae of the male, the anterior wing, and the shape of the ramus stigmaticus, are much more convincing than the criteria of Flanders (1935) and Meyer (1941) which were based on the pigmentation of the body, or the size ratio of different parts of the body. In a later work (1960), Quednau took the length of the individual development period in a temperature of 30°C and a relative humidity of 80% as the main species-differentiating criteria. On this basis he distinguished five groups, and from these, nine species. He eliminated the species *T. cacoeciae* March., incorporating part of it in *T. embryophagum* and part in *T. minutum.*

As early as 1941, Meyer, in his monograph, reported several races (*T. evanescens* Westw.) where the length of time for the development of individuals under the same conditions varied markedly (Meyer 1941, page 19). From his results, which are of the same type as those taken into consideration by Quednau, one can conclude that a single species may include several ecological types. In discussing his results, Meyer writes: "It should be taken into consideration that not only different races, but even particular populations of one or another race of *Trichogramma* react to temperatures and moisture conditions outside of their optimum range, with means they possess varying ecological calues". We can assume that a temperature of 30°C and a relative humidity of 80 per cent do not fall within the optimum limits of the *Trichogramma* species and populations tested by Quednau. Experiments conducted in the present study (during the hatching of adults) showed considerable difference in the developing periods of different individuals of the parasite. The experiment was carried on exactly as described in Quednau's paper (1960), with the one exception that *Sitotroga cerealella* Oliv. was used as the host instead of *Ephestia kühniella* Zell. The presence of different periods of development of parasites in simultaneously infected host's eggs weakens the practical value of Quednau's criteria. The results obtained by Kadłubowski (1961) his experiment can be interpreted in a similar way. He found that the length of the developing period of *Trichogramma* in *Dendrolimus pini* L. eggs depends on the number of *Trichogramma* eggs present in one egg of the host. In the case of a large number of parasitic eggs in one host-egg, the period of development shortens and the number of *Trichogramma* with retarded development drops to a minimum. In the case of small number of parasites in the host-egg, however, the imagines of *Trichogramma* appear at a much later time in relation to the former, while the individuals with retarded development are, as a rule, very numerous.

These examples clearly show that the length of the developing period can not be practically used as the determinant in differentiating between *Trichogramma* species. It is also hard to accept Quednau's findings (1960, page 15) that the length of the development cycle of species of *Trichogramma* is fixed by heredity.

Telenga (1959a), using anatomical, morphological, and biological differences as a base, reduced all known species of *Trichogramma* in the USSR to three; *T. evanescens* Westw., *T. cacoeciae* March., and *T. embryophagum* Htg. He found that species of *Trichogramma* differ among themselves in the shape and color of fragmae, and also in the length of ovipositors.

There exist some contradictions between the results obtained by Quednau (1956) and by Telenga (1959a); for example, according to Quednau, *T. cacoeciae* is a species without males, while Telenga described this species as made up of both sexes. These differences of opinion become still more obvious with the appearance of a later paper of Quednau's (1960) where he disregards *T. cacoeciae* March. as a species and on the basis of the length of the development period attaches one part of it to *T. embryophagum*, and one part to *T. minutum*. With the above data in mind, an analysis was made of species of *Trichogramma* in Poland from the standpoint of the permanency of the traits pointed out by Telenga (1959a) and Quednau (1956, 1960). It turned out that some of these traits, such as the length of the ovipositor, the hairs on the anterior wing, the pigmentation of the body and other factors can change depending on the host and the conditions of breeding.

In order to identify species of *Trichogramma* mentioned in this paper, I took the following things into consideration: the shape and arrangement of aristas on the antennae of the *Trichogramma* males, the shape and color of the fragmae, the type of parthenogenesis, the pigmentation of the body in given conditions, and the species of host. Species divided on this basis also showed different reactions to bio-ecological tests. In the present experiments, the following aspects were taken into consideration: the number of generations, the sum of effective temperatures, the resistance to low temperatures, wintering requirements, dispersion, and the reactions of *Trichogramma* and the host to a change in density.

A short discription of the species investigated follows.

1. *Trichogramma evanescens* (Westwood 1833) = *T. evanescens* – Hase 1925, Schultze 1926, Marchal 1927, Salt 1934, Ščepetilnikova 1939, Ferriére 1947, Quednau 1956, 1960, Telenga 1959a, and *T. turkestanica*, Meyer 1941.

This species was reared from the eggs of *Barathra brassicae* L. collected in July of 1958 from the district of Lublin above the Bug River, and from the eggs of *Pieris brassicae* L. and *P. rapae* L. taken from the vicinity of Palmiry and Dziekanów near Warsaw.

The body color is brown to dark brown. The cirri on the antennae of the males have long aristae and are sparsely distributed. Only males hatch from the eggs of unfertilized females. This species is widely spread in Europe, living parasitically on the eggs of many species of insects, mostly butterflies. A rather exhaustive list of the hosts of this species was made up in 1925 by Hase. *T. evanescens* is a typical species inhabiting a field enviroment and, according to Telenga (1956), the appearance of this species in the orchard is sporadic. It may appear as a parasite in the eggs *Tortricidae*, but only when accompanied by a large increase in the population density of this host. *T. evenescens* can very often be found in the eggs of *Cassida nebulosa* L. in the orchard. *T. evanescens* belongs to the various geographically non-crossing forms. However after 8-12 months of development in the same conditions and with the same host, males and females from different localities copulate between themselves. It should be stated that the forms may differ considerably as regards fertilization, the sex ratio in the population, reaction to changes in relative humidity, adaptation to appropriate habitats, spreading, and behaviour of the imagines (Telenga 1959b).

On this basis, Telenga (1959b) differentiates between two such races (forms according to our interpretation) of *T. evanescens*: a parasite of the eggs of *Pieridae*, *T. evanescens pieridis*; and *T. evanescens typica*, a parasite of the eggs of *Noctuidae*, not living in the eggs of *Pieridae*.

T. evanescens spreads mainly by moving among plants, taking wing only at high temperatures (approximately 25°C). As many as seven generation may appear during one season in Polish climatic conditions (see chapter: "Individual development cycles and the number of generations in one year"). *T. evanescens* hibernates in the larval stage and stands the winter well. Peterson (1932), Meyer (1941), Telenga (1954) and Maslennikova (1959) have pointed out the existence of a larvae diapause stage in the case of *Trichogramma*. It has been determined that diapauze, in *Trichogramma*, can appear, it the development takes place in a temperature of approximately 10°C. Some parts of a wintering population of *Trichogramma* can stand a temperature of −30°C, or even −35°C below zero for a short period of time. *T. evanescens*, introduced in a garden in Łomna near Warsaw in 1958, hibernated successfully, and observations made in August of 1959 indicated that 83.5% of *Pieridae* eggs were attacked and 100% of the eggs of *Barathra brassicae*.

2. *Trichogramma cacoeciae* Marchal 1927 = *T. pallida* Meyer 1941, *T. pini* Meyer 1941; *T. embryophagum* Quednau 1956, Kadłubowski 1961; *T. cacoeciae* – Telenga 1959a and *T. evanescens* – Kadłubowski 1957; *Trichogramma* sp. – Koehler 1957; *T. cacoeciae pini* – Kolubajiv 1959; *T. cacoeciae* – Stein 1960; and *T. cacoeciae* – Gądek 1962.

The species were reared from the eggs of the following insects collected at the given times and places. *Carpocapsa pomonella* L. July 9, 1958, the vicinity of Warsaw; *Sitotroga carealella*, August, 1959, vicinity of Warsaw; *Acantholyda nemoralis* Thoms., May 22, 1960, district of Łódź; *Panolis flammea* Schiff., May 17–20, 1961, district Zielona Góra, Poznań, and Bydgoszcz; *Evetria buoliana* Schiff., July 13, 1961, district of Poznań. The females are yellow and the males a bright brown. The fragmae are transparent, somewhat sclerotic, and the tips are widely rounded. The cirri in the antennae of the males have short aristae and are relatively thick. From the eggs of unfertilized females hatch only males. This species is widely spread in Europe, appearing mostly in trees, and inhabiting moist areas. Telenga (1959a) distinguishes several races (forms according to our interpretation) in this species. If *T. cacoeciae* develops in the eggs of *Cacoecia rosana* L., only one or two generations occur from June to the end of the season. Experimentally, it is possible to cause a change of host, but this, in turn, will cause a change in the development cycle. During the development of this from in the eggs of *Cacoecia rosana*, males rarely appear, but are often found when developing in the eggs of other insects. *T. cacoeciae pallida* appears mostly in orchards as a parasite of *Carpocapsa pomonella* L. and other *Tortricidae*. *T. cacoeciae pini* is a typical parasite of the eggs of forest insects, mainly *Dendrolimus pini* and *Panolis flammea*.

T. cacoeciae differs from *T. evanescens* in it that it spreads more actively. It spreads uniformly through the crown of a tree, often makes flights to a distance of ten meters, and during one season may be found as far as five kilometers from the point of introduction. It spreads faster in an orchard of densely spaced well developed crowns than when the crowns are less well developed and more aparsely situated. Because of the intensive and rapid movement of *T. cacoeciae* from tree to tree, as well as its faster development, it is not necessary to introduce it in great numbers or to every tree when using it for biological control in orchards. The ratio of females to males in a population is 4:1. *T. cacoeciae* characteristically shows a high degree of fertilization, but in laboratory breeding conditions with *Sitotroga cerealella* eggs, the number of eggs attacked fluctuated between 50% and 70%. The per cent of the parasites hatching after even a short hatching period varied from 40% to 70%, while the per cent of *T. evanescens* imagines hatching was 90–95%. On the other hand, the per cent of the *S. cerealella* eggs attacked often surpasses 90%. Volkov (1959) explains this phenomenen by the fact that *T. cacoeciae* is a more specialized parasite than *T. evanescens*, and its larvae have higher food requirements *T. cacoeciae* is widely used in biological control in European and American orchards and forests.

3. *T. embryophagum* (Hartig 1838) = *T. cacoeciae* – Quednau 1956; *T. embryophagum* – Telenga 1959a. This species was raised from the eggs of *Malacosoma neustria* L. taken from the district of Lublin.

The body color is yellow, or a brownish yellow with a diagonal stripe across the base of the abdomen. The fragmae are transparent, somewhat sclerotic, with narrow, pointed, tips. From a yearly brood of this species raised on the eggs of *Sitotroga cerealella* there was not one male. This parasite appears in orchards and forests on dry terrain and is a species which is bred in the laboratory with difficulty. The per cent of the *S. cerealella* eggs attacked by this species does not exceed 50%. The per cent of fertilization with this species is lower than in the case of *T. evanescens* or *T. cacoeciae*, but taking into consideration the fact that the make up of this species is only males, the reproductive potential may be very high. Six full generations may develop yearly in Polish climatic conditions.

II. BIOLOGICAL AND ECOLOGICAL EXPERIMENTS

1. Individual development cycles and the number of generations in one year

The species of *Trichogramma* used in these experiments are insects repeating their cycle many times in a year and may produce as many as 14 generations yearly (southern Ukraine, Telenga 1959a). A short development cycle makes possible a rapid increase in the numbers of *Trichogramma*, which in turn encourages a wide use of it in the control of plant pests.

Times of hatching of the imagines of *T. evanescens* Westw. and *T. cacoeciae* March. from the eggs of *Sitotroga cerealella* Oliv. simultaneously attacked by the parasite

Tab. I

Temperature in °C	Date of egg laying by the parasite	Date of hatching of the imagines	Number of imagines	
			T. evanescens	*T. cacoeciae*
25	5.III.1961	14.III.1961 15.III.1961 16.III.1961	38 70 5	52 129 14
30	21.III.1961	28.III.1961 29.III.1961	105 40	174 82

The results of these experiments on the development cycle, apart from the systematic value, can throw some light on biocenotic relations, and especially on the parasitehost relations, which may be an important factor in allowing a more rational use of *Trichogramma* in biological control. It should be noted that in natural conditions there will be some trouble in ascertaining the time of appearance of consecutive generations from the host egg. Starting with the second or third generations of *Trichogramma* in the orchard overlapping of the most intensive hatching periods of the respective generations was observed in the orchard. This is most evident, if *Trichogramma* is simultaneously developing in the eggs of several hosts. The time of development in different species of hosts may also vary, as was shown among others by Hase (1925). Even in the case of the development of parasites in the eggs of one species of host we often see discrepancies in the development time of individuals. It was found to be true in the present experiments (Tab. I). The fresh eggs of *S. cerealella* were placed in an incubator[1] along with *Trichogramma* for one

[1] This incubator is a device specially built for artificially hatching eggs, but without artificial heat.

hour. Next, the eggs infested by *Trichogramma* were placed in one of two compartments, one having a temperature of 25°C and the second 30°C. The relative humidity in both cases was 80%. The adult insects which appeared from the eggs were counted six times a day. Two species of *Trichogramma* were considered in the experiments; *T. evanescens* and *T. cacoeciae*.

The above data showed considerable differences in the time of development among individuals of the same species, living in the eggs of the same host in stable conditions. Kadłubowski (1961), investigating the times of appearance of *Trichogramma* from simultaneously infested eggs of *Dendrolimus pini* received similar results. He founds that the time of flight from the egg is dependent on the intensity of infestation of the eggs of the host of parasites in one egg causes the period. A large concentration of development to be shortened. Differences in the times of flight in his experiments were as great as 15 days.

Micro-climatic conditions in the crowns of the trees exert considerable influence on the length of the development period. Various conditions of lighting, moisture, and temperature (Kušnirenko and Černych 1959) also exert an influence on the development of the parasite in host eggs distributed in the crown of a tree. Still a larger variation occurs from temperature changes with different amplitudes of fluctuation. The problem of temperature changes was more precisely examined by Mikulski (1940–1947); the results of these tests were confirmed by Cromadska (1949). Mikulski showed that changes in temperature cause a retarded development during the extremes of the temperature range and an accelerated development in the optimum middle part of the range.

The examples given above point out the difficulties present in finding the number of *Trichogramma* generations in natural conditions. In the present study the experiments were made mostly with the purpose of finding the number of generations produced in one season by the three different species, as well as the sum of the effective temperatures. The experiments were considerably simplified with the hope of at least partially eliminating the various factors affecting the time of development of individuals of *Trichogramma*.

Observations of the times of appearance of subsequent generations were made on parasites developing in the eggs of *S. cerealella* with the exception of one generation which was reared on the eggs of *Barathra brassicae* and emerged in July or August. The use of the eggs of a natural host is a basic requirement, the purpose of which is to prevent the degeneration of the parasite. Three to five thousand parasites were placed first in test tubes, then in the specially built incubator. The data necessary to figure the sum of the effective temperatures for each generation was obtained from meteorological observations continuously conducted at Dziekanów Leśny. The meteorological observation point is 8 meters from the incubator. The thermometers were on the same level as the test tubes containing the developing *Trichogramma*. Meteorological observations were made 3 times a day in accordance with time set by the State Institute of Meteorology

Times of hatching of individual generations of *T. evanescens* imagines and the sums of the effective temperatures

Tab. II

Generation	Years 1958			1959			1960			1961		
	1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
I	15. V-30. V	19. V	56.2	14. V-17. V	15. V	65.2	1. V-7. V	4. V	70.2	3. V-17. V	10. V	77.8
II	2. VI-12. VI	7. VI	130.5	8. VI-14. VI	11. VI	134.1	4. VI-10. VI	6. VI	128.3	5. VI-15. VI	9. VI	131.9
III	25. VI-3. VII	28. VI	123.8	29. VI-5. VII	3. VII	134.4	22. VI-1. VII	25. VI	134.6	20. VI-4. VII	27. VI	132.1
IV	13. VII-18. VII	15. VII	132.2	13. VII-19. VII	16. VII	142.7	13. VII-21. VII	17. VII	132.1	15. VII-24. VII	19. VII	135.7
V	23. VII-7. VIII	2. VIII	132.7	26. VII-3. VIII	30. VII	142.4	28. VII-8. VIII	2. VIII	125.5	4. VIII-16. VIII	9. VIII	137.7
VI	16. VIII-27 VIII	21. VIII	129.5	13. VIII-20. VIII	16. VIII	146.0	16. VIII-13. IX	26. VIII	126.1	27. VIII-12. IX	3. IX	133.2
VII	5. IX-26. IX partial hatch	16. IX	121.9	8. IX-19. IX	13. IX	133.3	24. IX-22. X partial hatch	7. X	119.6	9. IX-19. X partial hatch	3. X	97.5
Total			826.8			898.5			836.4			845.9

1 — beginning and end of hatch, *2* — time of most intensive hatching, *3* — sum of effective temperatures.

Times of hatching of individual generations of *T. evanescens* imagines and the sums of the effective temperatures

Tab. III

Generation	1959			1960			1961		
	1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
I	10. V-15. V	13. V	56.8	18. V-24. V	21. V	118.8	2. V-14. V	8. V	77.8
II	6. VI-14. VI	10. VI	130.2	7. VI-15. VI	11. VI	122.0	5. VI-12. VI	9. VI	131.9
III	27. VI-2. VII	30. VI	131.1	23. VI-12. VII	3. VII	122.2	25. VI-1. VII	27. VI	132.1
IV	12. VII-18. VII	15. VII	143 7	16. VII-24. VII	20. VII	121.4	15. VII-23. VII	18. VII	131.5
V	26. VII-3. VIII	30. VII	152.7	2. VIII-12. VIII	6. VIII	126.3	5. VIII-12. VIII	8. VIII	129.8
VI	13. VIII-20. VIII	16. VIII	146.0	20. VIII-1. IX	28. VIII	127.2	27. VIII-8. IX	2. IX	134.8
VII	7. IX-18. IX		138.0	26. IX-6. XI partial hatch	9. X	98.5	19. IX-18. X	7. X	108.0
Total			898.5			836.4			845.9

1, 2, 3 – see Tab. II.

Times of hatching of individual generations of *T. evanescens* imagines and the sums of the effective temperatures

Tab. IV

Generation	Years					
	1960			1961		
	1	*2*	*3*	*1*	*2*	*3*
			90.3			77.8
I	10.V-16.V	14.V		11.V-16.V	13.V	
			129.0			142.7
II	5.VI-14.VI	8.VI		5.VI-16.VI	10.VI	
			141.2			147.6
III	27.VI-10.VII	2.VII		27.VI-3.VII	1.VII	
			139.2			148.7
IV	15.VII-28.VII	22.VII		20.VII-3.VIII	26.VII	
			139.1			153.4
V	8.VIII-16.VIII	12.VIII		14.VIII-2.IX	18.VIII	
			136.2			141.2
VI	27.VIII-13.IX	9.IX		9.IX-23.IX	15.IX	
			61.2			34.8
Total			836.2			845.9

1, 2, 3 — see Tab. II.

and Hydrology. The effective temperature totals were calculated, taking 10°C as the physiological zero, according to Ščepetilnikova's (1939) data.

The hatching times and the effective temperature totals are presented in Tables II (*T. evanescens*), III (*T. cacoeciae*), and IV (*T. embryophagum*). The days between the dates of maximum flight intensity of two consecutive generations are considered when calculating the total effective temperatures. By the term, maximum intensity of flight, is understood the time when the maximum numbers of living individuals can be found in the incubator. When giving the hatching dates of consecutive generations, the hatching dates occurring during generation overlap were eliminated. As the data presented (Tab. II, III) show, the effective temperature total of one generation (*T. evanescens* and *T. cacoeciae*) is an average of 122°. Seven generations develop with an effective temperature total of 850°, while a lower temperature total will allow only a partial hatch of the seventh generation. *Trichogramma* (*T. embryophagum*) demands an effective temperature of 140° for the development of one generation and with a yearly total of 840°, six full generations develop (Tab. IV). The development of the first and last generations usually differs from the above norm, which is derived from summer generations. The development of the first generation completes even if the minimum temperature falls below 10°C. At these temperatures the autumn generation always goes into the diapause period. In view of these data it is very likely that the physiological zero is not stable and may very from the norm, at least in the case of spring and autumn generations. This question has not been investigated.

In laboratory conditions with a stable temperature and 75–80% relative humidity, the effective temperature total is considerably higher than in field conditions (arred for *T. evanescens*) it amounts to 150–160.

The differences between results obtained in natural conditions and those obtained in the laboratory (aside from differences given in the introduction) can be explained by the fact that in natural conditions, due to a low night temperature (especially in spring and autumn) the average 24 hour temperature may not exceed the physiological zero (Tab. V). Nevertheless, the development proceeds

The development of *T. evanescens* in laboratory conditions

Tab. V

Number of replications	Number of females in one replication	Temperature in °C	Time of development in days	Sum of effective temperatures
3	200	16	26	156
3	200	20	16	160
4	400	25	10	150
4	200	30	8	160

in day time. The differences between the total effective temperatures of spring and autumn generations and summer generations can also be explained by this fact.

2. The effect of low temperature[2]

The purpose of these experiments was to determine the differences in the resistance of the various *Trichogramma* species to low temperature and the possibilities of their hibernation in Polish climatic conditions. Papers discussing the questions of resistance and the required hibernating conditions of *Trichogramma* are scarce and they concern only one species, *T. evanescens*. The publications of Telenga (1954) and Maslennikova (1959) deserve attention.

In the present study, the experiments were conducted from the 20th of January, 1960 to the 28th of February, 1960. Active and dormant larvae (in the eggs of *Sitotroga cerealella* stored at room temperature) were placed in test tubes and through a time period of 40–50 minutes the temperatures in the respective tubes were lowered by steps to –15, –20, –25, –30, and –35°C. When the air temperature in the test tubes reached the temperatures mentioned, the test was suspended and the test tubes returned to room temperature

[2] Some of these results were presented at the Conference on Biological Control in Warsaw, 1960 (Kot 1962).

surroundings, where they remained until the imagines appeared. The air temperatures in the test tubes were measured with thermocouples as formerly described (Kot 1958). The temperatures were lowered by the use of "dry ice" (solid carbon dioxide).

Larvae in the diapause period were obtained from the infested eggs of *S. cerealella* wintering in natural conditions, while active larvae were reared in the laboratory. The mortality rates of the active and dormant larvae were calculated on the basis of the number of imagines hatched. Three species were considered during the experiments; *T. evanescens*, *T. cacoeciae*, and *T. embryophagum*. They were reared from the eggs of insects occurring in natural conditions. The results of the conducted experiments are presented in Tables VI and VII.

The species most resistant to low temperatures is *T. embryophagum* (Tab. VI). On the comparison basis of the individuals not subjected to low temperatures, the mortality rate of the dormant larvae of *T. embryophagum* at a temperature of −30°C was 77.4%. In the same conditions larvae of *T. evanescens* reached a mortality rate of 97.9%, while *T. cacoeciae*, the least resistant species, was completely eliminated at this temperature. A part of the active larvae of all three species (Tab. VII) can still endure a temperature of −20°C, but they all die at a temperature of −25°C. The active larvae of *T. evanescens* showed the lowest survival percentage in relation to the experimental control larvae (Tab. VII).

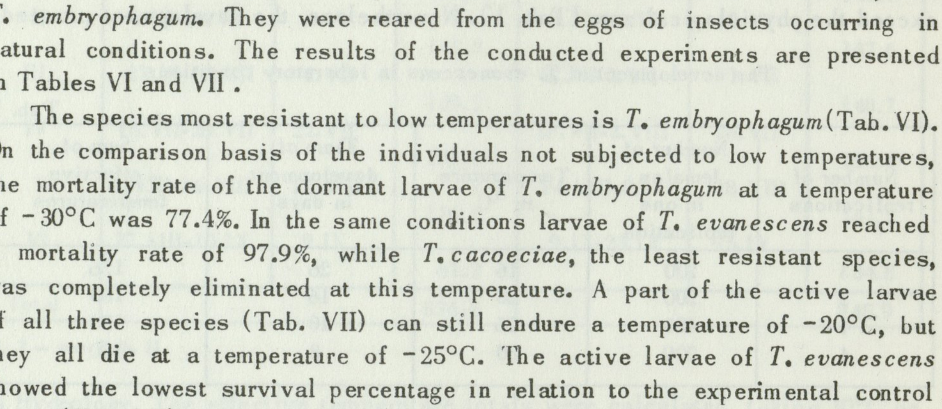

Fig. 1. Mortality curves of *Trichogramma* in relation to temperature

1 — dormant *Trichogramma*, *2* — active *Trichogramma*

The mortality curves (Fig. 1) plainly show the acceptable limits for cooling active and dormant *Trichogramma* larvae. According to the graphs, the temperature limit before mortality is 10°C higher for active larvae than for dormant larvae.

The influence of the action of short periods of low temperature on the survival of *Trichogramma* larvae in the diapause stage

Tab. VI

Temperature in °C	*T. embryophagum*				*T. evanescens*				*T. cacoeciae*			
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
+ 25	478	226	47.3	0	800	389	48.6	0	800	160	20.0	0
− 15	328	152	46.4	1.9	500	231	46.2	4.9	500	102	20.4	2.0
− 20	250	107	42.8	9.5	300	132	44.0	9.5	300	19	16.3	18.5
− 25	150	65	43.3	8.5	300	102	34.0	30.0	300	44	14.7	26.5
− 30	150	16	10.7	77.4	300	3	1.0	97.9	300	0	0.0	100.0
− 35	150	0	100.0	100.1	300	0	0.0	100.0	300	0	0.0	100.0

1 — number of attacked *S. cerealella* eggs, *2* — number of hatching imagines, *3* — percent of hatching imagines, *4* — mortality (percent) in relation to control experiments (25°C).

Tab. VII

The influence of the action of short periods of low temperature on the survival of active *Trichogramma* larvae

Temperature in °C	*T. embryophagum*				*T. evanescens*				*T. cacoeciae*			
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
control + 25	107	82	76.6	0	600	325	54.3	0	300	169	56.3	0
− 15	522	304	58.2	24.0	600	291	48.5	10.7	300	144	48.0	14.7
− 20	531	299	56.3	26.5	600	168	28.0	48.4	300	126	42.0	25.4
− 25	462	0	0	100.0	600	0	0	100.0	300	0	0	100.0

1, 2, 3, 4 — see Tab. VI.

As it is pointed out (Tab. VI, VII), the dormant larvae which hibernated in natural conditions suffered mortality losses during the winter. Dormant larvae of *T. embryophagum* and *T. evanescens* showed higher survival in our conditions than that of the larvae of *T. cacoeciae*. While the survival rate of these first two species was close to 50%, it was barely 20% in the case of *T. cacoeciae*. Similar results were obtained for larvae in the diapause stage examined after a considerably longer period of 38 days (Tab. VIII).

The survival of *Trichogramma* larvae in the diapause period checked after 38 days (6.IV.1960) following the end of the experiments presented in Tab. VI and VII

Tab. VIII

Species	Number of host's eggs attacked	Number of imagines hatching	Survival in per cent
T. embryophagum	172	82	47.7
T. evanescens	500	222	44.4
T. cacoeciae	500	103	20.6

Because of the fact that the given survival experiments concern individuals reared in the specially built incubator, and reared with an unnatural host (*Sitotroga cerealella*) it can be assumed that in natural conditions the mortality rate of dormant larvae is considerably lower. Taking this into consideration, the spring population of parasites should not be less than 50% of the autumn population in our conditions. However, as the results in the chapter "Invasive tendencies of *Trichogramma* in relation with changes in its numbers in the orchards" show, the size of the spring population is far below 50% of the preceding autuman population. In view of this, one can assume that the main reason for the decrease in the population of *Trichogramma* in the spring is an insufficient number of autumn layed eggs (of the host) in the orchard during the period of flight of the last generation of *Trichogramma*.

3. Dispersal of *Trichogramma*

Experiments concerning dispersal have much practical value in connection with methods of introduction, but they also are valuable in explaining certain dependencies in the host-parasite relationship (Kot 1960). Many research workers have worked with the dispersal characteristics of *Trichogramma*, including Hase (1925), Hinds, Osterberger and Duglas (1933), Steenburgh (1934), Alekseev (1936), Sobol and Gluchova (1937), Meyer (1941), Telenga and Ščepetilnikova (1949) and Volkov (1959).

These authors were interested mainly in the influence of wind and temperature on the direction and range of the dispersal of *Trichogramma* introduced in a given place. The experiments included the species *T. evanescens* and *T. cacoeciae.* Most of the authors mentioned above agree in principle as regards the influence of these factors on the dispersal range of the parasite. A strong wind causes passive spreading, while high temperatures (25–30°C) increase active flights of the parasites which considerably increase the general dispersal range.

Steenburgh (1934), on the basis of experiments conducted in the orchard, reached the conclusion that the direction of dispersal depends on the direction and speed of the wind. With the wind speed below 7 km an hour, *Trichogramma* can fly against the wind, but in a wind of 7–21 km an hour, or a speed higher than the maximum flight speed of the parasite, it will drift with the wind. According to the data of Meyer (1941) in an orchard with dense crowns and a sufficient number of the eggs of *Carpocapsa pomonella,* the dispersal of *Trichogramma* will be at a minimum. With a strong wind, there will be a passive dispersal in the direction of the wind.

On the basis of observations[3] in fields and orchards, an increase in the radius of dispersal was observed, depending on the strength of the predominant wind. It was observed that during a strong wind, the *Trichogramma* individuals were not eager to lay eggs, hiding under leaves or in crevices in the bark of the tree.

Conducting experiments concerning dispersal, the object was to learn the nature of, independent, of wind, the active dispersal of the parasite introduced to fields, orchards, and wood. For this reason experiments were conducted on days with very little wind. The main concern was in finding the extent of horizontal and vertical dispersal of individual species as well as the influence of the density of the host's egg deposits on dispersal. The test consisted of placing the eggs of *Sitotroga cerealella,* analysing the degree of infestation of these eggs, as well as the extent of infestation of the eggs of a natural host.

a. The effect of the density of the host's egg deposits on the dispersal of *Trichogramma*

Experiments concerning the effect of the density of the egg deposits of the host on the dispersal pattern of *Trichogramma* in cabbage were caried out at Łomna near Warsaw in July, 1958; in oats during May, 1959; and in mixed green feed (buckwheat – oats – lupine) in September, 1959. The eggs of *Sitotroga cerealella* were placed along lines running to the four directions of the compass from the point of introduction of *Trichogramma* (Fig. 2). The eggs were glued to smal pieces of thin cardboard and fastened to a leaf or a string. Each of the

[3] These results were partially presented at the XXVII meeting of the Polish Entomological Society in Szczecin in 1959.

four lines consisted of three rows in which the pieces of cardboard were placed in a checkerboard pattern. Each experiment was conducted simultaneously in

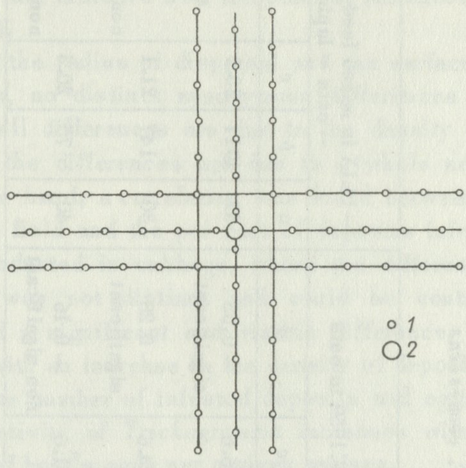

Fig. 2. Sketch of the distribution of egg deposits of *Sitotroga cerealella* Oliv. in fields designated for experiments over the dispersal of *Trichogramma*
1 – egg deposits, *2* – introduction of *Trichogramma*

three fields. In field No. 1 eggs were distributed every meter (in cabbage, every 2 meters); in field No. 2, every 5 meters; and in field No. 3, every 10 meters. The distance between individual rows in each field was the same as the distance between egg deposits in the rows. In the center of each field 20,000 *Trichogramma* were introduced, the cards holding the eggs were removed and inspected after 1 week (in cabbage after 5 days).

In working out the derived data, resulting from analysis of the eggs of the host, comparison was made of the radii of dispersal, the field surface of dispersal the number of attacked deposits and eggs in the deposits, as well as the coefficient of distance and the number of attacked host's eggs in each experiments.

The coefficient of correlation (r_{xy}) between the distance from the place of introduction of *Trichogramma* (x), and the number of attacked eggs of the host (y) were calculated using the following equation:

$$r_{xy} = \frac{\sum_{j=1}^{\eta_1} \sum_{i=1}^{\eta_2} (x_i - \bar{x})(y_j - \bar{y})}{N \delta x \delta y}$$

Dispersal characteristics of *T. evanescens*

Tab. IX

Field No.	Density of the host's egg deposits in the field	10–15.VII.1958 in cabbage				17–25.V.1959 in oats				7–14.IX in mixed feed-buckwheat(– oats – lupine)			
		a	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
1	every 1 m	30	1305	36.6	– 0.45 significant	34	1974	36.6	– 0.55 significant	39	1011	23.0	– 0.26 significant
2	every 5 m	28	537	38.9	– 0.43 significant	35	290	24.6	– 0.28 significant	30	147	21.1	– 0.19 non significant
3	every 10 m	40	375	36.0	– 0.40 significant	35	163	21.6	– 0.16 non significant	40	75	20.3	– 0.33 non significant

a – maximum dispersal radius in m, *b* – number of eggs attacked, *c* – per cent of the deposits under parasitical attack, *d* – coefficient of correllation between distance and the number of attacked eggs.

where x_i is the value of the variable of distance, y_j is the value of the variable of the number of infested eggs, x and y – the average of these values, δx and δy the deviation from the standard values of x and y, n_1 is the number of infested eggs, n_2 is the distance from the point of introduction of *Trichogramma*, $N = n_1 + n_2$ (Tab. IX).

When comparing the radius of dispersal and the surface of dispersal in the various experiments, no distinct synonymous differences can be found. It is doubtfull if the small differences are due to the density of the egg deposits, but more probably the differences are due to a whole series of other abiotic factors. On the other hand, a correlation was found between the density of the egg deposits in the field and the per cent of deposits infested. Except for the first experiment conducted in cabbage, where the difference in the number of deposits attacked was not distinct and could be contributed to error the experiments showed a significant and visible difference, pointing to the conclusion that along with an increase in the density of deposits in the field, there is an increase in the number of infested deposits and eggs in the deposits. In other words, the activity of *Trichogramma* increases with an increase in the number of deposits of host's eggs per a given surface.

It can be assumed, then, that the density of the host population is one of the most important factors influencing the numerical relations between the entomophagous parasite and its hosts. A high degree of effectiveness can not be expected from the introduction of parasites if the host in present in insignificant numbers. This is also pointed out, by observations noted while using *Trichogramma* for the control of harmful insects (*Plutella maculipennis* and *Pieris brassicae*) in 1958 near Warsaw (Kot 1959). Eggs of *P. maculipennis* were collected from one of the cabbage fields for breeding purposes, thus decreasing the population density of this pest. Following the introduction of *Trichogramma*, the number of the infested eggs was 24.8%; while in the rest of the fields, where the number of *P. maculipennis* eggs was greater, the per cent of infestation reached an average of 73.4–75.5%.

The explanation for this could be as follows; with a larger number of host's eggs per unit of surface, the parasite spends less energy looking for eggs. But this is a simplification, since the mechanics of this have not been tested exactly, and only a more exact biocenotic study will give the correct answer. Results of experiments concerning the influence of the *Trichogramma* population density on its development and the degree of infestation of the host eggs show that the parasite – host relationship, in this case, is very complicated (Sandner and Kot 1962).

In the results presented (Tab. IX) it was found that a fairly significant correlation also existed between the number of the infested *Sitotroga cerealella* eggs and the distance from the *Trichogramma* introduction point. The coefficient of correlation between this distance and the number of infested eggs in the deposits in the field increases with an increase in density. A larger coefficient of correlation in the fields where eggs were placed at one meter distance, in comparison to fields with less or density of egg deposits, indicates that with a fairly dense distribution of deposits the eggs on territory close to the place of releasing of the parasite were mainly attackted while with a decrease in the dens ity of the deposits, eggs on the dispersal area of *Trichogramma* were more uniformly infested.

b. The direction and limits of the dispersal of *Trichogramma*

When investigating the correlation between the dispersal characteristics of *Trichogramma* and the density of host's egg deposits, an uneven dispersion of the parasite in relation to the directions of the compass was always found (Tab. X, XI, XII). The intensity of dispersal of *T. evanescens* was determined

Number of attacked eggs of *S. cerealella* in relation to directions (cabbage field, 10–15.VII. 1958)

Tab. X

Field No.	Distribution of egg deposits in the field	Number of eggs attacked			
		East	West	North	South
1	every 2 m	641	106	222	336
2	every 5 m	39	31	88	199
3	every 10 m	24	13	62	475
Total		704	150	372	1010

Number of attacked eggs of *S. cerealella* in relation to directions (oats field, 17–21. VI. 1959)

Tab. XI

Field No.	Distribution of eggs deposits in the field	Number of eggs attacked			
		East	West	North	South
1	every 1 m	465	290	357	862
2	every 5 m	19	74	81	116
3	every 10 m	57	32	12	62
Total		541	396	450	1040

on the basis of the number of attacks on *S. cerealella* eggs. The area lying to the south and east of the place of the parasite's introduction was most intensively infested by *T. evanescens*. This can be easily understood if it is considered that *Trichogramma* shows a positive phototaxis. The same phenomenon can be observed in the case of *T. cacoeciae*; when introduced to apple or plum trees,

Number of attacked eggs of *S. cerealella* in relation to directions
(buckwheat-oats-lupine field, 7–14.IX.1959)

Tab. XII

Field No.	Distribution of egg deposits in the field	Number of eggs attacked			
		East	West	North	South
1	every 1 m	331	30	46	604
2	every 5 m	10	28	13	24
3	every 10 m	88	1	4	54
Total		429	59	63	682

it attacks mainly the southeast part of the crown (Kot 1962a, Wiąckowski and Kot 1962).

The results of experiments concerning vertical dispersal of the three species in tree crowns (see chapter "The vertical dispersal of *Trichogramma*") confirm the above data. Here considerable difference was observed between the degree of infestation of eggs placed on the north and south sides of a tree crown (Tab. XIII).

Number of attacked eggs of *S. cerealella* in tree crown
in relation to directions

Tab. XIII

Species	Number of attacked eggs	
	southern side of the crown	northern side of the crown
T. evanescens	879	414
T. cacoeciae	848	392
T. embryophagum	959	203

In this case as well as in the case of vertical dispersal an important role is played by light. The most intensively lighted parts of the tree crown are the southern parts and there the largest number of attacked deposits and eggs were found. This can be most easily seen by observing *T. embryophagum*, a species with a very marked phototaxis. As can be seen from the data presented (Tab. XIII) the number of eggs attacked by *T. embryophagum* in the southern part of the crown is close to five times the number attacked in the northern part. When using *Trichogramma* it should be introduced to the northern and lower part of the crown. With a uniform distribution such as that used while controlling *Carpocapsa pomonella* (Kot 1962a) and *Laspeyresia funebrana* Tr.

(Wiąckowski and Kot 1962) the infestation of the southern side was almost three times greater than of the northern side.

The data of many authors are similar in regard to the dispersal range of *T. evanescens*. Usually, the maximum dispersal radius of *Trichogramma* does not exceed 50 meters. Meyer (1941) presenting data pertaining to the dispersal of *Trichogramma*, pointed out the fact that attacked eggs are often found as far as 100 meters from the point of introduction of *Trichogramma*, but emphasized that these attacks may be due to *Trichogramma* individuals appearing in nature. During experiments investigating the influence of the density of egg deposits on dispersal characteristics in nine fields, the radius of flight did not exceed 40 meters (Kot 1960).

There have been many experiments conducted in the Soviet Union (Meyer 1941, Telenga 1956, Volkov 1959) concerning *T. cacoeciae*. This species feeds on the eggs of bush and tree insect pests and is more active than *T. evanescens*. Experiments were conducted in the orchard near Warsaw in 1959 and 1960 as well as in woods in 1961 and 1962. The experiments were made with the purpose of observing the distance of dispersal and the distribution of attacked eggs in the tree crowns (see chapter "The vertical dispersal of *Trichogramma*") trough the analysis of *Carpocapsa pomonella* eggs. In July 1960, the maximum dispersal of *T. cacoeciae* (one generation) was found to be 60 meters. Experiments conducted near Drawski Młyn near Poznań (1960, 1961) showed a possible dispersal range of 50–70 meters for one generation of *T. cacoeciae*. An exact fixing of the dispersal range could not be done, because the results were affected by the presence of wild forms of this species. In Polish climatic conditions 6 to 7 generations of *Trichogramma* develop and from this it should be expected that the distance of active flight during one season would not exceed 500 meters.

c. The vertical dispersal of *Trichogramma*

During the biological control of *C. pomonella* with *Trichogramma*, it was found that different species attacked eggs in different parts of the crown. Eggs attacked by *T. cacoeciae* were fairly uniformly distributed through the entire crown, with insignificant preponderance in the upper parts. Eggs attacked by *T. embryophagum* were grouped in the upper part of the crown, while the eggs attacked by *T. evanescens* were grouped in the lower parts.

Keeping this in mind, in July, 1961, special experiments were conducted with the purpose of examining the vertical dispersal of the three species of *Trichogramma*. The tests were carried on in the following manner. In the vicinity of Dziekanów Leśny, near Warsaw, four similar birch trees were chosen. Small cards, each with 200 *Sitotroga cerealella* eggs glued to them were fastened to leaves in the upper, middle, and lower parts of the crown. Than, 10,000 imagines of *T. evanescens*, *T. cacoeciae*, and *T. embryophagum* were introduced in the center of three trees respectively, the fourth tree serving as a control tree. After four days, the cards were collected and the number of deposits and eggs attacked were counted (Tab. XIV).

Vertical dispersal of *Trichogramma* in birches
(12–20. VII. 1961)

Tab. XIV

	T. evanescens			*T. cacoeciae*			*T. embryophagum*		
	part of crown								
	top	middle	bottom	top	middle	bottom	top	middle	bottom
Number of collected deposits	43	33	46	37	36	45	47	47	42
Number of deposits with eggs attacked by *Trichogramma*	7	18	21	10	17	19	33	29	3
Total number of attacked eggs in the deposits	30	263	997	182	657	401	455	699	8
% of eggs attacked in parts of the crown in relation to the total number attacked	2.3	20.4	77.3	14.7	52.9	32.4	39.2	60.1	0.7

As can be seen from the results (Tab. XIV), the vertical distribution of individual species in this case was very similar to that in the experiment on the control of *C. pomonella* (Kot 1962). The number of deposits and eggs attacked by *T. evanescens* was greatest in the lower parts of the tree crown. Of 46 deposits attacked by *T. evanescens* in all parts of the crown, 21 deposits were found in the lower part. On the basis of the total number of attacked eggs, the per cent of attacked eggs lying in the lower parts was 77.3; in spite of the fact that the *Trichogramma* was introduced in the center part of the crown, which increased the possibility of infestation of eggs lying at that hight. The distribution of deposits and eggs attackted by *T. cacoeciae* was more uniform, with certain preponderance in the middle and upper part of the tree crown.

The largest number of deposits and eggs attacked by *T. embryophagum* was found in the upper and middle sections of the crown. In the lower part of the crown, only 0.7% of the total number of attacked eggs were found.

4. The role increased population density of *Trichogramma* and its host

Cognition of the mutual parasite-host relationship contributes to considerable progress in the biological control of harmful pests. This subject has been of interest, in the case of *Trichogramma* and its host, to Salt (1934, 1936, 1941), Quednau (1956), Sandner and Kot (1962). In the paper of these last authors certain regularities in the effect of the population density of the parasite on its development were examined. They confirmed, basically, the results presented in publications concerning several varieties of beetles (Sandner 1958, 1959a, 1959b) and *Heterodera schachtii* (Sandner and Fedorko 1960). It is to be noted that there are distinct differences among the *Trichogramma* species tested. It appears that:

1) Along with an increase in the density of the introduced imagines, the number of offspring of the parasite reaches a peak (maximum), then decreases with each species possessing its own curve of the number of offspring hatching. The maximum number of *T. evanescens* offspring hatched with a density of 10–15 *Trichogramma* females for 100 *Sitotroga cerealella* eggs. With *T. cacoeciae* the largest hatch is obtained with a density of 5 to 15 females for 100 eggs in this case there is a wide fluctuation. The largest number of offspring are obtained with *T. embryophagum* at a rate of 35 females for 100 *S. cerealella* eggs.

2) With an increase in the density of *Trichogramma* the number of surviving hosts decreases again to a certain limit. The lowest number of hosts survive with densities of 15 and 35 females to 100 eggs in the case of *T. evanescens* and *T. embryophagum* respectively, that is, at the densities necessary for a maximum hatch of offspring from these species. With a deviation (increase or decrease) in density of the parasite from values given above the number of surviving hosts increases. The smallest numbers of surviving hosts were on the average, 10 individuals in the case of *T. evanescens*, and 8 individuals in the case of *T. embryophagum*. Concerning the species *T. cacoeciae*, the curve showing the relationship between an increase in the parasite population density and a decrease in the number of hosts is similar to an exponential curve. It seems that the constant decrease in the number of surviving hosts in relation to the increase in the *T. cacoeciae* population density is connected with the large number of damaged or dried out eggs with a high population concentration. However, in all three species, almost always some of the hosts survive. Only when experimenting with *T. cacoeciae* 100% mortality of the hosts was found for 12 times with a large number of the eggs dried out or damaged.

3) The number of over infested eggs dried out, or damaged[3], increases with

[3] Dried out or damaged eggs are those which have been punctered by the female parasite, but in which, for various reasons, no eggs have been deposited. The *Trichogramma* also puncture the egg and suck out the contents. Some of the eggs are damaged

increased population density of all three parasitic species, showing the minimum, or practical optimum density. With the highest density (50 males for 100 hosts), the number of eggs over infested, dried out or damaged reached an average of 38.4% for *T. evanescens*, 74.2% for *T. cacoeciae*, and 54.4% for *T. embryophagum*.

4) Along with an increase in density, a relative increase in the concentration of males was observed, as well as an increase in the number of underdeveloped males. Still, this does not occur in direct proportion to the density, as was found by Salt (1936). The increase in the number of males in proportion to females was most evident in the species *T. cacoeciae*. With one female to 100 eggs of *S. cerealella* the ratio of males to females was 1:3, whereas with a density of 50 females to 100 eggs, the ratio was 1: 1.5.

5. Preliminary trials in the classification of the hosts of *Trichogramma*

The *Trichogramma* genus includes species of polyphagous parasites living in the eggs of a hundred of hosts, mainly from the order *Lepidoptera*. They also attack the eggs of insects from other orders, including *Hymenoptera*, *Neuroptera*, *Diptera*, *Coleoptera* and *Hemiptera*. Even in the eggs of certain species from the order *Dermaptera*, the larvae of *Trichogramma* can develop. The larvae of *Trichogramma* will develop not only in freshly laid eggs, but also in eggs where the development of the embryo is quite advanced (Burzyński and Kot 1963). Still in spite of a wide adaptality in regard to food, only the eggs of a few groups of hosts are attacked by all of the species of *Trichogramma*. One of these "universal" groups are the butterflies belonging to the family *Noctuidae*. Even within the individual species of *Trichogramma* there exist certain ecological forms showing a strong preference for certain hosts (Telenga 1959a, 1959b).

With the purpose of determining the degree of attractiveness of various hosts to the species of *Trichogramma*, the following method in conducting an experiment was used. *T. evanescens*, raised from the eggs of *Barathra brassicae*, *T. cacoeciae* raised from the eggs of *C. pomonella*, and *T. embryophagum*, raised from the eggs of *Malacosoma neustria*, were the species used there in the experiments. A total 50–100 host's eggs were glued to cards and put in the incubator containing the eggs of *S. cerealella* and the appropriate species of *Trichogramma* imagines. There was always a surplus of *S. cerealella* eggs in the incubator. The temperature in the laboratory was maintained between 23° and 25°C during the day and 14–15°C at night, while the relative humidity fluctuated between 70% and 80%. The per cent of infestation by *Trichogramma*

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during counting, which is very hard to prevent. Such damaged eggs dry out and there hatches neither the offspring of the host nor of the parasite. They also take on a yellow color. With a high density (50 males for 100 *S. cerealella* eggs) there are sometimes as many as 97% of such eggs.

was calculated when the eggs had turned black. Experiments were also conducted in test tubes, with the one difference, that there were no *S. cerealella* eggs present in the tubes.

On the basis of the relative number of eggs attacked, the following classification of hosts was established.

1) Attractive host (++). The undamaged eggs in the incubator were attacked within the limits of 5–80%, and in the test tubes from 80–100%.

2) Relatively attractive host (+). The sound eggs in the incubator were attacked within the limits of 5–50%, while attacked individuals in the test tubes exceeded 50%.

3) Non attractive hosts (0). The sound eggs in the incubator were not attacked in excess of 5%, and attacked individuals in the test tubes was less than 50%.

4) Others species, not hosts (–). The eggs showed no trace of infestation. The results of the biological experiments presented (Tab. XV) show the physiological and not ecological host preference of *Trichogramma*, which means that in certain ecological conditions, the classification might be set up differently. A very important thing in such a situation is a quick adaptation of the *Trichogramma* to the host with which it has contact. In laboratory conditions, *Trichogramma* quickly adapting to a given host later shows a greater preference for that host. For example, *Trichogramma* reared in 1958 from the eggs of *C. pomonella* as late as 1962 showed a tendency to attack eggs of that host, although for a period of four years it had been raised on the eggs of *S. cerealella*. A similar situation was observed with *Trichogramma* reared in 1959 from the eggs of *Malacosoma neustria*.

Examining the presented data from the point of view of attractiveness for individual groups of hosts, it can be stated that most of the species from the family *Noctuidae* are attractive for all species of *Trichogramma*. In the relatively attractive category most of *Tortricidae* are present. Representatives of hosts from other systematic goups show various degrees of attractiveness. Analizing the individual *Trichogramma* species in regard to food selectiveness on the basis of the conducted tests, distinct variations can easily be found (Tab. XVI). Of the three tested species, the least selectivity was shown by *T. evanescens*. From the 38 species of hosts examined in the experiment, 28 were attractive or relatively attractive, 8 nonattractive, and 2 species were avoided by *T. evanescens*. In second position regarding the selectivity is *T. cacoeciae*. Out of 39 species used, 26 were attractive or relatively attractive, 11 non-attractive and 2 were avoided. In the case of *T. embryophagum* the smallest number of attractive or relatively attractive hosts (22) was found. From 37 tested hosts, six were avoided by this species.

The completion of this analysis allowed a more accurate evaluation of the possibilities of using the various species of *Trichogramma* in forestry and agriculture practices.

Classification of the hosts of *Trichogramma*

Tab. XV

No.	Species of hosts	*T. evanescens*	*T. cacoeciae*	*T. ambryophagum*
1	*Acronicta rumici* L.	++	++	++
2	*Agryroploce variegana* F.	0	+	+
3	*Agrotis segetum* L.	++	++	++
4	*Aporia crataegi* L.	+	0	−
5	*Acantholyda nemoralis* Thoms.	0	+	+
6	*Barathra brassicae* L.	++	++	++
7	*Bupalus piniarius* L.	+	+	+
8	*Choristoneura murinana* Hb.	+	+	+
9	*Caliroa limacina* Retz.	−	0	0
10	*Carpocapsa pomonella* .	+	+	+
11	*Cephalica abietis* L.	0	+	+
12	*Dendrolimus pini* L.	0	+	+
13	*Evetria buoliana* Schiff.	+	++	+
14	*Euxoa exclamationis* L.	++	+	+
15	*Euproctis chrysorrhoea* L.	−	0	0
16	*Hyloicus pinastri* L.	0	+	+
17	*Laspeyresia funebrana* Tr.	+	0	+
18	*Laspeyresia dorsana* F.	+	0	−
19	*Mamestra dissimilis* Knoch.	++	+	+
20	*Malacosoma neustria* L.	+	+	++
21	*Oscinosoma frit* L.	+	+	−
22	*Operophthera brumata* L.	+	+	0
23	*Orgyia antiqua* L.	0	0	0
24	*Pegomyia hyoscyami* Panz.	+	−	−
25	*Pieris brassicae* L.	+	0	0
26	*Pieris rapae* L.	+	0	0
27	*Polia oleracea* L,	++	+	+
28	*Polia pisi* L)	++	+	+
29	*Pristiphora pallipes* Lep.	0	0	0
30	*Pteronidea ribesii* Scop.	0	0	0
31	*Panolis flammea* Schiff.	++	++	++
32	*Pyrausta nubilalis* Hbn.	+	+	0
33	*Phalera bucephala* L.	+	0	0
34	*Phytometra gamma* L.	++	+	+
35	*Phalonia epilinana* Zell.	+	+	+
36	*Plutella maculipennis* Curt.	+	0	−
37	*Rhyacia c-nigrum* L.	++	++	+
38	*Synchloe daplidice* L.	+	−	−
39	*Sitotroga cerealella* Oliv.	+	+	+
40	*Tortrix viridana* L.	+	++	+

++ attractive, + relative attractive, 0 unattractive, − others (not hosts).

Groups of hosts arranged by numbers according to their attractiveness for individual species of *Trichogramma*

Tab. XVI

Groups of hosts	Species of *Trichogramma*		
	T. evanescens	*T. cacoeciae*	*T. embryophagum*
Attractive (++)	10	8	6
Relative attractive (+)	18	18	16
Unattractive (0)	8	11	9
Others (not hosts) (–)	2	2	6

6. Invasive tendencies of *Trichogramma* in relation to changes in its numbers in the orchard

An important aspect in the biological control of plant pests through the use of entmophagous parasites is the longlasting effectiveness and the economy of the operation. These characteristics depend to a large degree on the concentration and colonization of beneficial insects through an artificial increase in the numbers of the already existing insects by the introduction of alluring plants, providing food for the imagines of the parasites, providing places for living or hibernation, the introduction of additional hosts, etc. The application of these techniques demands a through knowledge of biology, and especially a knowledge of the causes of fluctuation in the concentration of beneficial species.

In approaching a discussion of methods and results of experiments conducted in this area, attention should be driven to important difficulties often met during the interpretation of obtained data. The cause of these difficulties in the fact that there may be very many factors influencing changes in the concentration of insects in nature. This situation is especially complicated where parasites are concerned. Let us give several examples of factors limiting the numbers of *Trichogramma* in different periods.

Between the maximum concentration of hatching of the first and second generations a distinct break can always be observed. During this break, the eggs of even the most attractive hosts (e.g. *Noctuidae*) are not attacked. For this reason it would be easy for an incoordination in the appearance of the fertile females and the egg deposits of the host to occur. Unfavorable atmospheric conditions low temperature, rain, strong wind without doubt retard an increase in the numbers of *Trichogramma*. Still, one of the main factors limiting the number of parasites is a lack of host eggs in certain parts of the year. For this reason, for instance, most of the individuals of the last generation of *Trichogramma* die in the orchard.

The experiments were conducted in a small orchard (3 ha), in which there had been no chemical means of control used since 1957. The orchard was located near Warsaw; the majority of the trees were apple trees "Reinette" with an average age of 20 years. In approaching the experiments on the concentration of *Trichogramma* numbers in the orchard, some basic methodical difficulties were encountened. For example, the sweep-net method, often used in entomological and biocenotical experiments does not give satisfactory results in this kind of experiments. Some information was derived by analizing the number of hosts' eggs actually developing in the orchard, as well as the degree of their infestation. This method gives good posibilities of detecting the actual number of *Trichogramma*, but is difficult to affect. The eggs of different species of insects have various degrees of attractiveness for individual species of *Trichogramma*. Depending on the size and attractiveness of the eggs, 1 to 80 larvae may parasite in them. These factors and similar factors complicate an evaluation of the results and comparisons. Considering the above mentioned difficulties involved in working out material obtained in this way, the change of egg numbers curves (Fig. 3) (mainly of *Spilonota ocellana* F.) were used for presentation of the results during 1960, because at this time numbers were quite high, and

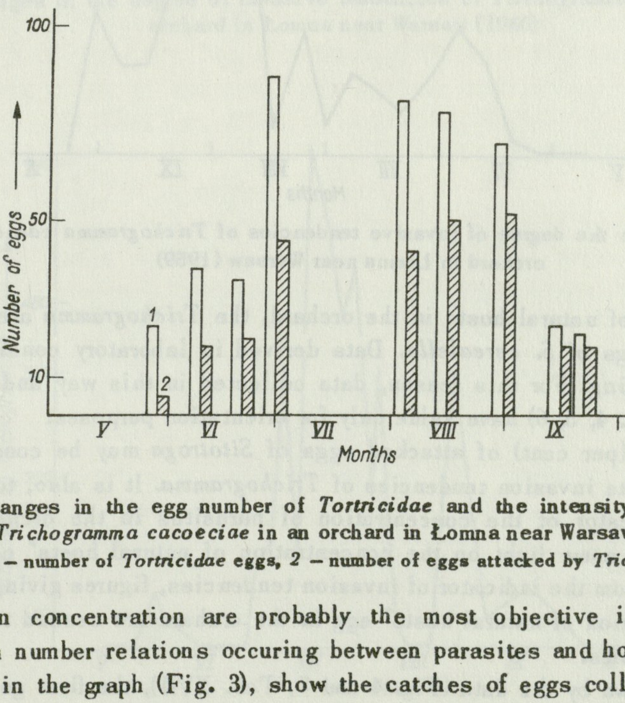

Fig. 3. Changes in the egg number of *Tortricidae* and the intensity of infestation by *Trichogramma cacoeciae* in an orchard in Łomna near Warsaw (1960)

1 – number of *Tortricidae* eggs, 2 – number of eggs attacked by *Trichogramma*

changes in concentration are probably the most objective indication of the changes in number relations occuring between parasites and hosts. The results presented in the graph (Fig. 3), show the catches of eggs collected during two weeks. The quantitative material was collected by examining every week 900 to 1000 leaves, and in the case of *C. pomonella*, 100 apples.

In later experiments pertaining to the changes in numbers of *Trichogramma*, a method based on the exposure of egg of *S. cerealella* was applied. The eggs were glued to cards in quantities of 200 to a card and placed in thee crowns. Every week 24 cards were placed in each of 2 trees, beginning from the middle of May (the flight of the first generation in the orchard) until the middle of October. The eggs were mainly attacked by *T. cacoeciae*, and only toward the end of August and the beginning of September 21 eggs, attacked by *T. evanescens*, were found in the lower parts the crowns. This method is fairly simple, allowing observations to be carried out systematically. It does not render great difficulties in working out the fairly uniform material. Still, the degree of infestation of *S. cerealella* eggs by *Trichogramma* does not always reflect the number of individuals of the latter in the orchard. When there is a considerable

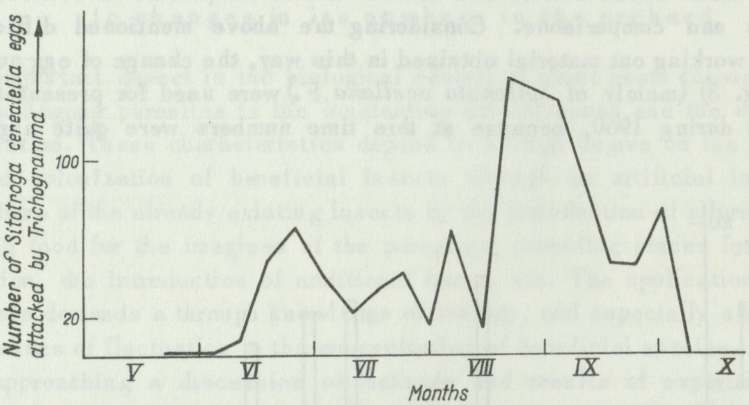

Fig. 4. Changes in the degree of invasive tendencies of *Trichogramma cacoeciae* in an orchard in Łomna near Warsaw (1959)

number of eggs of natural hosts in the orchard, the *Trichogramma* are not eager to attack the eggs of *S. cerealella*. Data derived in laboratory conditions also confirm this finding. For this reason, data collected in this way and presented in the graps (Fig. 4, 5, 6) have value only for orientation purposes.

The number (per cent) of attacked eggs of *Sitotroga* may be considered as an indicator of the invasion tendencies of *Trichogramma*. It is also, to a certain degree, an indicator of the concentration of parasites in the orchard. These indicators throw some light on the concentration of natural hosts' eggs in the orchard. Aside from the indicator of invasion tendencies, figures giving a picture of the concentration of natural hosts' egg in the orchard are needed to correctly interpret the results.

As it is shown by the data (Fig. 4 and 5, Tab. XVII), the first generation of *Trichogramma*, which appears in our conditions about the 20th of May, does not attack the eggs of *S. cerealella* at all. This is connected with the low number of parasites present and the still sufficient at this time number of eggs of natural

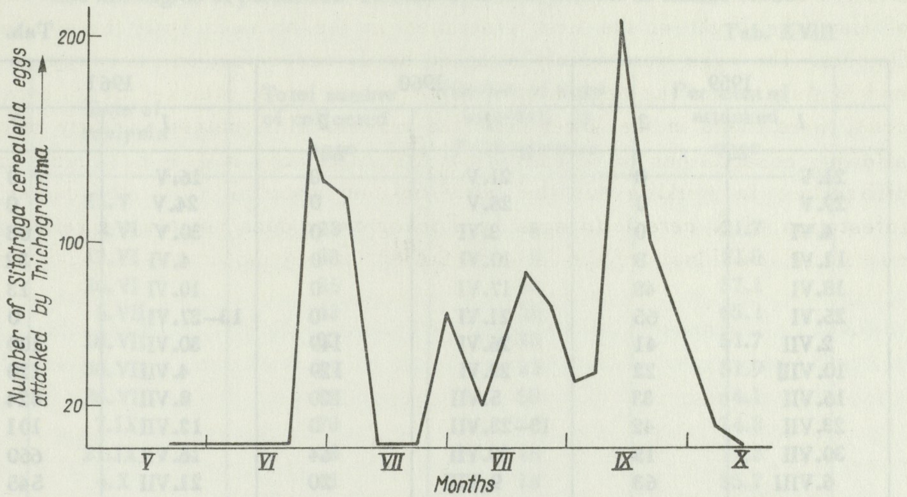

Fig. 5. Changes in the degree of invasive tendencies of *Trichogramma cacoeciae* in an orchard in Łomna near Warsaw (1960)

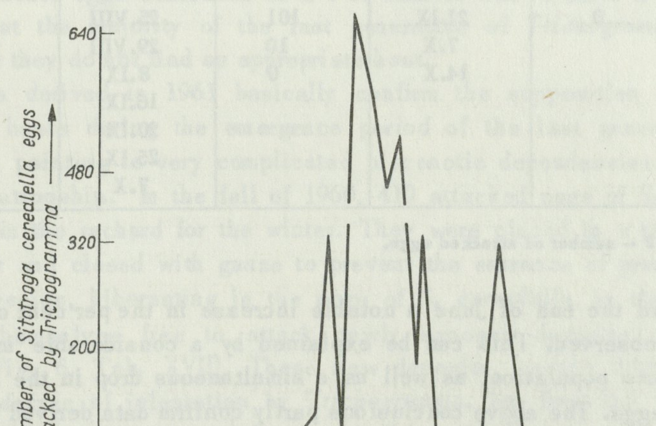

Fig. 6. Changes in the degree of invasive tendencies of *Trichogramma cacoeciae* in an orchard in Łomna near Warsaw (1961)

The results of analysis of the eggs of *S. cerealella* placed in an orchard in Łomna

Tab. XVII

1959		1960		1961	
1	*2*	*1*	*2*	*1*	*2*
21.V	0	21.V	0	16.V	0
29.V	0	28.V	0	24.V	0
4.VI	0	3.VI	0	30.V	63
11.VI	8	10.VI	0	4.VI	32
18.VI	48	17.VI	0	10.VI	13
25.VI	65	21.VI	0	13–27.VI	0
2.VII	41	26.VI	149	30.VI	100
10.VII	22	29.VI	129	4.VII	120
16.VII	33	5.VII	120	8.VII	324
23.VII	42	13–23.VII	0	12.VII	101
30.VII	15	30.VII	64	16.VII	660
6.VIII	63	9.VIII	20	21.VII	545
14.VIII	14	13.VIII	42	25.VII	459
21.VIII	141	20.VIII	84	29.VII	519
4.IX	129	26.VIII	68	4.VIII	177
17.IX	47	2.IX	32	6.VIII	332
24.IX	46	7.IX	36	11.VIII	35
1.X	73	14.IX	205	14–22.VIII	0
8.X	0	21.IX	101	25.VIII	165
		7.X	10	29.VIII	296
		14.X	0	8.IX	32
				16.IX	55
				20.IX	65
				25.IX	53
				7.X	0

1 – date of analysis *2* – number of attacked eggs.

hosts. Only toward the end of June a notable increase in the per cent of eggs attacked can be observed. This can be explained by a considerable increase in the *Trichogramma* population, as well as a simultaneous drop in the number of natural hosts' eggs. The above conclusions partly confirm data derived from an analysis of the concentration and degree of infestation of natural hots' eggs. At the end of July and in August, although the number of *Trichogramma* is considerably higher than in the preceding period (Fig. 3, Tab. XVIII), the degree of infestation of *S. cerealella* eggs decreases because of the increasing concentration of the eggs of *Tortricidae* (the hatch of butterflies from the second generation). At the end of August and during September, again an increase in the infestation of *S. cerealella* eggs is observed which is connected with an increase in the frequency of appearance of *Trichogramma* (Fig. 4, 5) as well

Changes in the frequency of appearance of the eggs of natural hosts and the degree of parasitical activity by *Trichogramma* in Łomna (1960)

Tab. XVIII

Date of analysis	Total number of collected eggs	Number of eggs attacked by *Trichogramma*	Per cent of attacked eggs
21.V			
3.VI	23	6	21.7
17.VI	38	8	21.0
26.VI	35	20	57.1
5.VII	43	28	65.1
18.VII	87	45	51.7
30.VII	81	42	51.9
26.VIII	78	50	64.1
7.IX	70	52	74.3
21.IX	23	18	78.3
4.X	21	18	85.7

as a shortage of the eggs of natural hosts during this time. For example, in 1960, of 4,000 eggs exposured on 14th of September, 205 were attacked, in comparison to an average of 46 for the whole period (from 15th of May). The number of natural hosts' eggs decreases to 1/4 of what it was in July. It can be assumed then that the majority of the last generation of *Trichogramma* normally die because they do not find an appropriate host.

Data derived in 1961 basically confirm the supposition of a scarsity of natural hosts during the emergence period of the last generation of *Trichogramma*, pointing to very complicated biocenotic dependencies in the parasite-host relationship. In the fall of 1960, 410 attacked eggs of *S. cerealella* were placed in the orchard for the winter. They were placed in a test tube wrapped in paper and closed with gauze to prevent the entrance of predaceous insects. *T. cacoeciae*, hibernating in the eggs of *S. cerealella*, in the spring of 1961 found themselves free to attack newly exposed deposits of *S. cerealella* eggs (Fig. 6, Tab. XVII). These new deposits, on the 24th of May showed a high degree of infestation by *Trichogramma*, but from the 13th to the 27th of June, there were no attacks on the *S. cerealella* eggs. Probably the cause of this was the break which occurred between the emergence of the first and second parasite generations. From the 30th of June, the invasion tendency indicator was very high and remained at this level until the 11th of August. During this period, we see only an insignificant decrease in the invasion tendencies, this being noted on the 12th of July. It can be assumed that in this period there appeared a large number of *Trichogramma* in relation to the number of natural hosts' eggs.

During August, 14–22, the exposed deposits were not attacked, which may indicate that there was present a considerable number of natural hosts' eggs more attractive than those of *S. cerealella*. Near the end of August and during the first part of September the invasion tendencies again rose which points to a lack of natural hosts.

The distinct difference between the invasion tendency indicator in the orchard in 1961 and those of former years should be noted. It is very probable that the cause of these differences was the 410 attacked eggs of *S. cerealella* which remained through the winter from the 1960 autumn. Because of this there was a noticeable hatch of the first generation, something which was not observed in former years. Because of the fact that a considerable number of *Trichogramma* individuals hibernated in the eggs of *S. cerealella* in a small section of the orchard where experiments were conducted, in the spring in this section a large number of parasites was observed. It is probable, then, that trough the introduction of surplus hosts (for example, in the form of *S. cerealella* eggs) we can change the number relationship between the parasite and the host in favor of the parasite.

III. EXPERIMENTS IN THE USE OF *TRICHOGRAMMA* FOR PEST CONTROL

1. A short history of the use of *Trichogramma*

Trichogramma has been known to science for 130 years, but only at the beginning of the twentieth century did it start to interest scientists as something to be used in pest control.

The first trials at breeding and using *Trichogramma* in the control of *C. pomonella* were conducted by Radeckij (1911, 1912, 1913), Mokrzecki and Bragina (1916). Radeckij, in 1911, started experiments on the introduction of *T. evanescens* Westw. from the Astrakhan province of Turkistan. After the parasite had multiplied, he introduced it to the orchard. According to Radeckij's data (1912, 1913) the introduced parasite acclimatized, multiplied, and effectively destroyed pests. Before its introduction, Radeckij did not find any *Trichogramma* in the Turkistan orchards. Mokrzecki and Bragina (1916) started trials in the biological control of *C. pomonella* in the Crimea orchards, using two species of *Trichogramma*, *T. semblidis* Aur. and *T. fasciatum* Perk. These parasites, to a considerable degree, limited the number of *C. pomonella* in the test orchard.

The first experiments in the biological control of cabbage pests through the use of *Trichogramma* were carried out by Voelkel (1925) in the vicinity of Berlin. On the 18th of July, 30 females of *T. evanescens* were released; these, multiplying, from the 27th of August completely checked the development of *Barathra brassicae* and *Pieris brassicae*. Close to 100% of the eggs of these harmful insects were attacked by *Trichogramma*.

In the 1920's, there appeared comprehensive monographe of *Trichogramma* (Hase 1925, and Schultze 1926) which summed up the then known information on that subject.

Only after Flanders (1927, 1928) worked out a method of mass rearing parasites on the eggs of *S. cerealella* did the application of *Trichogramma* in biological control take place on a large scale. The eggs of *S. cerealella* can be obtained from a culture in unlimited numbers at any time of the year, which makes possible intensification in the breading of *Trichogramma*, as well as increasing the number of experiments pertaining to its effectiveness in the biological control of a whole series of cultivated crop pests.

As early as 1927, Flanders used *T. minutum* reared on the eggs of *S. cerealella* for the control of *C. pomonella*, with an effectiveness of 79.9%. List and Davis (1933) conducted a series of experiments in Colorado. In the spring of 1930, they introduced to the orchard for the control of *C. pomonella* approximately 2 million *Trichogramma* individuals reared on the eggs of *S. cerealella*. In the autumn the analysis showed that 70.27% of the *C. pomonella* eggs were attacked by the parasite, but in spite of this, only 15% of the apples were undamaged.

During the 1930's, intensive experiments were run carried out on the influence of various factors on the development of *Trichogramma* (Zulueta 1927, Norris 1930, Flanders 1931, Eidmann 1934, Salt 1934, 1935, 1936, Steenburgh 1934, Meyer 1941, Ščepetilnikova 1937, 1939).

In the Soviet Union experiments were started on a wide scale after the organization of the Biological Control Laboratory at the All-union Institute of Plant Protection in Leningrad in 1933. The work of this center was summed up in Meyer's monographical work (1941), in which he gave a rather exact review of world literature. He individuated, a series of races of *T. evanescens* differing in their biological and ecological properties. He thouroughly discusses the influence of biotic and abiotic factors on *Trichogramma*, carefully describing the methods of mass breeding, and methods of application in the control of plant pests, as well as results of experiments in the control of *C. pomonella*, *Laspeyresia funebrana*, *Polychrosis botrana* Schiff., *Pyrausta nubilalis* Hbn., *Laspeyresia nigricana* Step., *L. dorsana* F., *Phalonia epilinana* Zell., *Loxostege sticticalis* L., *Agrotis segetum* L., *Heliotis obsoleta* F., *Oscinella frit* L. and a number of orchard pests.

After the Second World War, when the danger of excessive chemical application was starting to be realized, interest in biological control and especially control with *Trichogramma* grew even more rapidly. Post-war literature devoted to this parasite is quite common, and so we are limited here to a discussion of some of the most important works, which were carried on in countries neighbouring Poland. In the Soviet Union, every year 4–5 billion *Trichogramma* individuals are bred and introduced to the countryside for control purposes. In connection with this detailed instructions were worked out for the breeding and application of *Trichogramma* to control plant pests (Telenga and Ščepetilnikova 1949). For example, biological control of *Agrotis segetum* was carried out lately on an area of one-half million ha (Ščepetilnikova and Fedorinčik 1962). A series of Telenga's works devoted to the problems of diapause and wintering conditions (Telenga 1954), later supplemented by Maslennikova (1959), biology and ecology (Telenga 1959a), as well as the problem of races of the separate species of *Trichogramma* (Telenga 1959b), to a considerable degree influenced the development of the use of *Trichogramma* in biological control, not only in the Soviet Union, but also in other countries.

In Germany, mainly in Berlin-Dahlem, Mayer conducted comprehensive experiments over the problem of the parasite-host relationship. The most thorough investigation is made over the selectivity of food and the change in behaviour of *Trichogramma* under the influence of the host (Quednau 1955, 1956, Mayer and Quednau 1959, Mayer 1960). In the last of these papers, Mayer sums up the work of his laboratory, presenting the following results.

1) Abiotic factors influence not only the length of the parasite development cycle, but also its fertility.

2) The frequency of hatching of imagines and the flight activity depend to a large degree on the temperature and light.

3) Eggs laying is conditioned by optical, chemical, and mechanical stimuli, with the result that the host may be completely ignored if the appropriate factors are not present.

4) The selection of host's eggs depends not so much on the species of host, as on the physical characteristics of the eggs.

5) With a more dense parasite population, the behaviour of *Trichogramma* will change, with the result that the offspring will show a reaction of a new type, having new ecological adaptations. This can explain to a certain degree the existence of different species and ecological types of parasites in the same breeding conditions.

6) A complete knowledge of the behaviour of *Trichogramma* may be the key to selecting appropriate forms of parasites for use in biological control and the working out of mass breeding methods.

Work on taxonomy of the genus *Trichogramma* has been also conducted in the Mayer's laboratory (Quednau 1956, 1960). Stein (1960) have his attention to the use of *Trichogramma* in the biological control of *C. pomonella* with an effectiveness of 35% to 65%. Stein (1961) also conducted experiments on the dispersal of *Trichogramma* in fruit tree crowns, as well as the influence of certain fungicides and insecticides on parasites introduced to the orchard.

Experiments with *Trichogramma* have been conducted in Czechoslovakia since 1957, mainly from the point of view of forestry needs. K o l u b a j i v (1959) describes the forest form, *Trichogramma pini* Mayer, reared on the eggs of *Cephalcia abietis* L. The intensity of infestation of the eggs of *C. abietis* by this form in 1957–1958 in the vicinity of Červena Jamă and Ještěd was 80%. Still, breeding trials with the eggs of *Leucoma salicis* L., *Tortrix viridana* L., and *Sitotroga cerealella* were not successful. With this information the author came to the conclusion that the forest race of the species *Trichogramma pini* is on rather advanced level of adaptation to the given host species. Taking into consideration data obtained during the mass breeding, Kolubajiv suggests that while preparing *Trichogramma* for biological control of a specific pest, an attempt should be made to get the initial material from the species which is to be the object of control, or from one related to it.

In Poland experiments on forest forms of *Trichogramma* were started in 1954 in Poznań (K a d ł u b o w s k i 1957). All of these experiments were presented in the paper of K a d ł u b o w s k i (1961). The author used *Trichogramma* obtained from the eggs of *Acantholyda nemoralis*, and reared on the eggs of *Dendrolimus pini*. The author examined the following problems; 1) "the capacity" of the *D. pini* eggs, 2) the role of the numerical relationship between the host substratum (eggs) and the parasite, 3) the selectiveness of the parasite in relation to the host, 4) the influence of the age of the host's egg on the "production" of the parasite as well as, 5) the possibilities of storing host eggs and dormant parasites. Besides this, the author presents results of experiments on the suitability of *Trichogramma* for the biological control of *Acantholyda nemoralis*, in which an effectiveness of 42% is obtained. The results are not entirely authoritative because of the small number of trees included in the experiment (6) and the small number of parasites introduced in one tree (600–800 individuals).

In 1957 a permanent *Trichogramma* hatchery was established at the Field Station of Institute of Ecology in Dziekanów near Warsaw using mainly the eggs of *S. cerealella*. Part of the work carried out with *Trichogramma* reared in Dziekanów was already published (K o t 1959, 1960, 1962a, 1962b, S a n d n e r and K o t 1962).

In 1960 experiments were conducted concerning the use of *Trichogramma* in the orchard of a Pomology Institute (W i ą c k o w s k i and K o t 1962, W i ą c k o w s k i and W i ą c k o w s k a 1962, W i ą c k o w s k i and others 1962). The experiments pertain mainly to the control of *Laspeyresia funebrana*.

2. Experiments in the control of *Plutella maculipennis* Curt., *Pieris brassicae* L. and *P. rapae* L. with *T. evanescens*

The first experiments on the control of cabbage pests with *Trichogramma* were conducted by V o e l k e l (1925). On the 18th of July he introduced females of *T. evanescens,* which multiplying, from the 27th of August completely checked the development of *Barathra brassicae* and *Pieris brassicae* (almost 100% of the pests' eggs were attacked). Starting in 1937, there were experiments conducted in many countries over the introduction of *Trichogramma* to vegetable gardens. The results of the experiments were various, but there was always a marked reduction in the number of pests. The results of the research on this problem done before the Second World War were fairly widely covered in Meyer's monographical work (1941).

The experiments which will be presented further in this paper are the first trials conducted in Poland on the use of *Trichogramma* for the control of vegetable garden pests. These experiments were conducted in the summer of 1958 with an early variety of cabbage („Pierwszy Zbiór") in a field of 1 ha (field No. 1) and on cabbage of a later variety (Amager – short stem), also in a field of 1 ha (No. 2), as well as on early cabbage in field No. 3 with an area of 0.75 ha, all near Warsaw. Each of the three fields was divided into two parts, one part serving as a control field and the second as the experimental section. *Trichogramma evanescens* was directed against three cabbage pests: *Plutella maculipennis, Pieris brassicae,* and *P. rapae.*

An attempt was made of the biological control of *P. maculipennis* through the use of *Trichogramma* was attempted only on early cabbage in field No. 1, while the control of *Pieridae* was carried out in all three fields simultaneously. Introductory tests showed no "wild" *Trichogramma* present on the terrain where the experiments were carried out. On the 15th of July, during the time of mass emergence of the second generation of *P. maculipennis,* 80,000 *T. evanescens* were released in one phase. For every 500–600 m^2 of the field area 4,000–5,000 *Trichogramma* were released (Fig. 7).

Five days after the introduction of *Trichogramma* an analysis of the *P. maculipennis* eggs was conducted. Deposits were collected from every tenth plant moving diagonally across the field. The number of attacked eggs were then counted in the laboratory (Tab. XIX). It can be seen that the percentage of attacked *P. maculipennis* eggs in the field with *Trichogramma* was 67%, while in the control field only 1.2% were attacked. During the first two observations no *Trichogramma* were found on the control field, but later they appeared; this probably means that they came from fields lying close to those in which *Trichogramma* had been introduced.

Beginning on the 25th of July, 1958, the number of caterpillars was counted on 20 cabbage heads. This was repeated three times during three days, and the number of caterpillars found totaled. In the experimental field as well as in the control field, 60 plants were examined (Tab. XX).

As a result of the introduction of *Trichogramma* the number of caterpillars was reduced 57.7% (Tab. XX). The above data indicate that even a one phase introduction of *Trichogramma* will bring profitable results in the control of

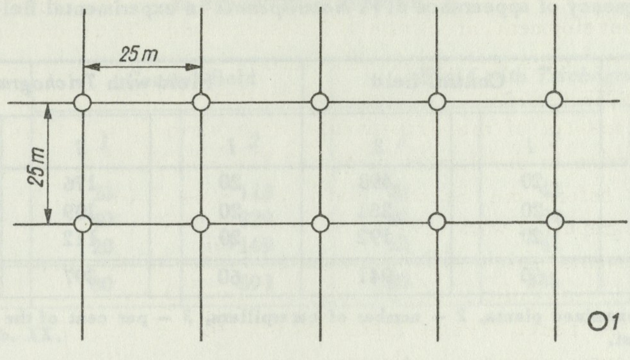

Fig. 7. Sketch of the distribution of imagines *T. evanescens* on the surface of the experimental fields

1 – introduction of *Trichogramma*

The degree of parasitical activity by *Trichogramma* on the eggs of *Plutella maculipennis* in field No. 1

Tab. XIX

Date of analysis	Control field			Field with *Trichogramma*		
	number of eggs in the sample	number of eggs attacked	per cent	number of eggs in sample	number of eggs attacked	per cent
20.VII	105	0	0	128	73	57.0
24.VII	114	0	0	213	158	74.2
29.VII	27	3	11.1	34	24	70.5
Total	246	3	1.2	375	255	68.0

P. maculipennis. The leaves and heads of the cabbage in the control field were full of holes, whereas the cabbage heads in the *Trichogramma* field were whole and the leaves were little damaged.

After the completion of the experiments with *P. maculipennis*, experiments on the control of *Pieridae* with *Trichogramma* were started. On the 29 of August, 1958, *Trichogramma* were introduced to all three experimental fields according to the above given scheme. Then the eggs were examined to find out the number attacked, but an exact diagnosis was made difficult by unfavorable weather conditions in the form of heavy rain; for this reason the results of the analysis will not be given. Presented, however, are the concentrations of the *Pieris brassicae* and *P. rapae* caterpillars in the control and experimental fields (Tab. XXI, XXII, XXIII).

As is shown by the results presented (Tab. XXI, XXII), in the fields with the early cabbage („Pierwszy Zbiór") and *Trichogramma*, the number of *Pieridae*

The frequency of appearance of *P. maculipennis* in experimental field No. 1

Tab. XX

Date of analysis	Control field		Field with *Trichogramma*		
	1	*2*	*1*	*2*	*3*
25.VII	20	498	20	176	64.6
28.VII	20	251	20	109	56.6
31.VII	20	192	20	112	41.7
Total	60	941	60	397	57.7

1 — number of examined plants, *2* — number of caterpillars, *3* — per cent of the decrease in the density of the pest.

The frequency of appearance of *P. brassicae* and *P. rapae* in cabbage in experimental field No. 1

Tab. XXI

Date of analysis	Control field		Field with *Trichogramma*		
	1	*2*	*1*	*2*	*3*
20.VIII	20	233	20	34	85.5
23.VIII	20	199	20	63	68.3
25.VIII	40	396	40	101	74.5
27.VIII	20	103	20	50	51.5
Total	100	931	100	248	73.4

1, 2, 3 see Tab. XX.

The frequency of appearance of *P. brassicae* and *P. rapae* in cabbage in experimental field No. 2

Tab. XXII

Date of analysis	Control field		Field with *Trichogramma*		
	1	*2*	*1*	*2*	*3*
20.VIII	20	658	20	135	79.5
23.VIII	20	618	20	137	77.8
25.VIII	40	924	40	142	84.6
Total	80	2200	80	414	81.2

1, 2, 3 — see Tab. XX.

caterpillars was reduced 73.4% and 75.5% in comparison to the control plot. In the field of later cabbage ("Amager" short stem), the number of caterpillars was reduced 81.2% (Tab. XXII). The high degree of effectiveness obtained with the late cabbage is probably due to the higher population density of *Pieridae*.

The frequency of appearance of *P. brassicae* and *P. rapae* in cabbage in experimental field No. 3

Tab. XXIII

Date of analysis	Control field		Field with *Trichogramma*		
	1	*2*	*1*	*2*	*3*
21.VIII	20	113	20	42	62.8
24.VIII	40	329	40	62	81.2
27.VIII	20	149	20	41	72.5
Total	80	591	80	145	75.5

1, 2, 3 – see Tab. XX.

In the late cabbage the population density was an average of 27.2 caterpillars for one plant, while in the early cabbage the density was 9.2.

3. Experiments in the control of *Carpocapsa pomonella* L.

C. pomonella is one of the worst orchard pests, necessitating the use of various control methods everywhere. Experiments concerning the use of *Trichogramma* against *C. pomonella* had been begun as early as at the beginning of the twentieth century (Radeckij 1912, 1913, Mokrzecki and Bragina 1916, List and Dewis 1933).

At the present, *Trichogramma* is being used for the biological control of *C. pomonella* in the United States and the Soviet Union, with trials being conducted in Germany, the Netherlands, and Poland.

Experiments in the use of *Trichogramma* for the control of *C. pomonella* in Poland were begun in 1959 on a farm near Łomna in an orchard of 23 ha. The predominant apple varieties in this orchard were "Reinette Landsberger" and "Boiken". In 1959 the orchard was divided into three parts: in the first section, on the 5th of June, *T. cacoeciae* was introduced at the rate of 1,500 individuals to one tree. In the second section, a chemical operation (dusting with a DDT preparation) was carried out on the 10th of June. The third part, for the purpose of comparison was left as a control plot.

The *Trichogramma* were placed in the orchard in test tubes covered with 1 mm^2 mesh gauze, thus allowing the imagines to exit from the test tube, but not allowing larger predacious insects or mites to enter. The *Trichogramma* were introduced to the orchard when 30% of the parasitical imagines had left the eggs.

The tubes were fastened to the north side of the tree crowns and to low branches. Such a system of placement gave the best results; the eggs of *C. pomonella* were uniformly attacked throughout the entire tree crown. In July and

August, the number of fallen, damaged and healthy fruits was counted, as well as the number of damaged and healthy on the trees (Tab. XXIV). The introduction of *Trichogramma* for the control of the first generation showed an effectiveness of 29.5%, while dusting one time with DDT that of only 9.8%. Such ineffective results might partially be explained by the fact that in our conditions the emergence of the first generation of *C. pomonella* continues for the whole month of June, and even the first part of July, which means that a single operation, be it chemical or biological, will not be entirely effective. A single introduction of *Trichogramma* achieved better results in this case than a single chemical operation, the decisive reason for this being the action by the offspring of the introduced parasite.

Results of experiments comparing the effectiveness of *T. cacoeciae* and DDT (Łomna 1959)

Tab. XXIV

	Section of orchard with an introduction of *Trichogramma*	Section of orchard dusted with DDT	Control section
Number of examined fruits	2542	1754	1290
Number of fruits damaged by *Carpocapsa pomonella*	942	830	677
Per cent of damaged fruits	37.0	47.3	52.4
Decrease in the number of damaged fruits in relation (per cent) to the control section	29.5	9.8	–

In 1960, in an orchard of 3 ha divided into three sections, 3,000 *Trichogramma* (1,500 at a time) were introduced in two phases to one tree on the 8th and 19th of June. *T. cacoeciae* was introduced to the first section of the orchard, *T. embryophagum* to the second, and *T. evanescens* to the third. From each of these sections 9 trees were chosen for observations with 17 being chosen from the control section. The extent of infestation by *Trichogramma* on the *C. pomonella* eggs was calculated on the 30th of June and the 10th of July, and a count of insects damaged by *C. pomonella* was carried out on the 12th and 18th of July. On the last of August the windfall was checked and August 22nd the yield was calculated (Tab. XXV).

The per cent of infestation of eggs by *T. cacoeciae* was approximately 68.2%, and that of *T. embryophagum* – 70.1%, and in the case of *T. evanescens*

Results of experiments comparing the effectiveness of three species of *Trichogramma* introduced in the orchard in Łomna 1960

Tab. XXV

	Section with *T. cacoeciae*	Section with *T. embryophagum*	Section with *T. evanescens*	Control section
Number of eggs found	315	318	213	320
Number of attacked eggs	214	223	130	0
Number of attacked eggs in the top section of the trees	113	171	21	0
Number of attacked eggs in the bottom section of the trees	101	52	109	0
Per cent of attacked eggs	68.2	70.1	61.3	0
Number of examined fruits	2064	1761	1462	3317
Number of damaged fruits	112	82	86	468
Per cent of damaged fruits	5.4	4.6	5.9	14.1
Decrease in the number of damaged fruits in relation to the control section (per cent)	61.5	67.0	58.4	0

the per cent of infestation was 61.0. It should be emphasised that the *Sitotroga cerealella* eggs attacked by *T. cacoeciae* were distributed more or less uniformly throughout the whole crown of the tree, with a small predominance of eggs in the upper parts. The eggs attacked by *T. embryophagum* were mainly grouped in the upper parts of the tree crown, while those attacked by *T. evanescens* were in the lower parts. This can be explained by the fact that *T. cacoeciae* reared from the eggs of *Tortricidae* is a species attracted to trees and possessing a less marked positive phototaxis than *T. embryophagum* reared from the eggs of *Malacosoma neustria*. *T. evanescens*, a typical field species, does not usually reach the upper parts of the crown, remaining near the ground.

Because of the fact that the preliminary experiments were conducted in 1959 and 1960, and that they showed a relative high effectiveness in controlling

C. pomonella, allowing higher yields, more extensive tests were conducted simultaneously in four orchards in 1961.

1) In a private orchard in Przegorzewice Nowe near Warka, a systematic chemical control was carried out according to recommendations.

2) In a private orchard near Warsaw, no chemical operations had been carried out for several years.

3) On a state farm near Warsaw, chemical operations were carried out irregularly, only during times of heavy invasions of pests or disease.

4) In an orchard at the Medical School's experimental station, at Łomna no chemical operations had been conducted since 1957.

T. cacoeciae, the species most uniformly distributed through out the tree crowns was introduced in these orchards. The main purpose in conducting these tests was to learn the degree of effectiveness of one and two phase introduction of *Trichogramma*, as well as a comparison of the effectiveness, of these operations in orchards where chemical operations had been used and in those where they had not been used. In former years it was found that the degree of infestation of the eggs of *C. pomonella* by *Trichogramma* is higher (compare data Tab. XXIV and XXV) than the comparative effectiveness of the operation evaluated on the basis of the amount of fruit damaged. Since the last mentioned fact is the most accurate indicator of the value of the operation, in 1961 the analysis was limited to counting the windfalls and calculating the yield. The amount of sound and damaged fruit was calculated every two weeks beginning the 30th of June. Between the 22nd and 30th of August the healthy and damaged fruit on the tree leaves was counted (Tab. XXVI). The most effective treatment turned out to be in the first orchard Przegorzewice Nowe where a two phase introduction of *Trichogramma* was carried out; the control trees had 25.7% damaged apples while the experimental trees had barely 8%. The effectiveness of the operation in relation to the control section was 68.9%.

In the second orchard, a two phase introduction of *Trichogramma* was also carried out, with introductions on the 4th and 10th of June totaling 3,000 individuals. This experiment showed 30.5% damaged fruit in the control section and 15.5% in the experimental section, this giving an effectiveness of 49.2% in relation to the control section.

In the third orchard a one phase introduction of *Trichogramma* on the 7th of June, with a density of 3,000 per one tree, showed 29. 1% effectiveness in relationship to the control section. The per cent of damaged apples in the control section was 15.8 while the section with *Trichogramma* had 11.2% damaged apples.

The experiment in the last orchard was a one phase introduction of *Trichogramma* on the 7th of June with a density of 2,000 per tree, and showed

Results of experiments in the control of *Carpocapsa pomonella* by the use of *T. cacoeciae* in 1961

Tab. XXVI

Place and date of experimets	Number of examined trees	Number of examined fruits	Number of fruits damaged by *C. pomonella*	Per cent damaged fruits	Decrease in the number of damaged fruits in relation to the control section (per cent)
Przegorzewice Nowe 6th and 14th VI	8	5512	442	8.0	68.9
Control	8	3399	874	25.7	–
Łomna, near Warsaw 4th and 10th VI	10	4546	703	15.5	49.2
Control	9	4517	1377	30.5	–
Łomna, second orchard 7th VI	9	2968	333	11.2	29.1
Control	8	1826	290	15.8	–
Łomna, third orchard 7th VI	6	1515	471	31.1	36.9
Control	6	2093	1032	49.3	–

an effectiveness of 36.9% in relations to the control part. On the control trees there was 49.3% damaged fruit and on the trees with *Trichogramma* 31.1%. This orchard in this year yielded very poorly; on most of the trees there was no fruit at all or only a small amount. Because of this, the entire population of *C. pomonella* was concentrated on the small amount of fruit present. So it can be seen that although the per cent of infestation of the eggs of *C. pomonella* was fairly high, the savings in yield were not significant.

4. Trials in the use of *Trichogramma* in the control of *Evetria buoliana* Schiff.

Evetria buoliana is a very serious pest of young pines. It destroys the young shoots, usually near the top and causes dwarfing and retarding of growth. In years with large *E. buoliana* populations, an entire area of young pines may be destroyed. Recently, the Department of Forest Protection in the Forestry Experimental Institute started inclusive experiments pertaining to this pest. Among other problems the possibility of using its natural enemies for control is being considered carefully. Koehler (1961), in 1946 observed a high degree of infestation of the eggs of *E. buoliana* by *Trichogramma* (for example, 75% in the vicinity of Drewnica near Warsaw). As a result of this, in 1961 he conducted preliminary tests in the control of *E. buoliana* in the vicinity of Drawski Młyn, where the frequent appearance of this pest was observed over a fairly large area. On the 3th of July, an average of 32 eggs per tree was found, counting only eggs on the main shoot and on the top whorl.

On the 30th of June and the 8th of July, *Trichogramma* was introduced to three different areas occupied by the pest. Among the pupae of *E. buoliana* collected on the 30th of June the imagines had emerged from 75% of the total. *T. cacoeciae* (300,000) were introduced to two areas which had been prepared for experiments on dispersal. On the above given dates, 1,000,000 *T. cacoeciae* and *T. embryophagum* were introduced on terrain designated for experiments on hibernation of parasites in the eggs of *E. buoliana*.

When examined on the 13th of July, effectiveness of the operations was found to be high (Tab. XXVII). It was not possible, however, to tell exactly how effective the operations were because of evidence of the presence of *Trichogramma* which had not been introduced in the experiment. This trouble was also encountered when trying to define the extent of the parasite's dispersal. On terrain near Drawski Młyn, the infestation of eggs by non introducet *Trichogramma* was about 60%. In spite of intensive action by *Trichogramma* already on the terrain, the introduction of laboratory reared parasites in three areas of forest raised the degree of parasitical activity over 20%. In light of the above data it can be supposed, that the use of *Trichogramma* for the control of *E. buoliana* has large possibilities.

Results from experiments in the control of *Evetria buoliana* with *T. cacoeciae* and *T. ambryophagum* in Drawski Młyn in 1961

Tab. XXVII

Number of surface	Species of *Trichogramma*	Number of *Trichogramma* individuals introduced	Number of examined eggs	Number of eggs attacked by *Trichogramma*	Per cent attacked eggs
I	*T. cacoeciae*	300,000	2056	1644	80.0
II	*T. cacoeciae*	300,000	2228	1976	88.7
III	*T. cacoeciae* and *T. embryophagum*	1,000,000	1593	1374	86.2
IV	Control	0	378	230	60.7

It should be noted that there was a lack of coincidence between the emergence of the parasite and the host, with the result that the *E. buoliana* eggs collected on the 25th and 30th were not attacked. Eggs attacked by the already present *Trichogramma* were found only after this period. Tied in with this is the fact that eggs layed by *E. buoliana* during the first period of swarming are not accessible for wild forms of *Trichogramma* because of the advanced development of the embryo. Because of this, introductions of *Trichogramma* should be made as soon as *E. buoliana* butterflies start to lay eggs.

5. Trials in the use of *Trichogramma* for the control of *Acantholyda nemoralis* Thoms.

Nunberg (1946) observed the eggs of *Acantholyda nemoralis* attacked by *Trichogramma* for the first time in Poland in Puszcza Niepołomicka. Koehler in 1957 conducted a number of observations, coming to the conclusion that *Trichogramma* completely destroys high concentrations of *A. nemoralis* . Even in pine forests of one species, with scrubby underbrush, growing on poor soil and with sparse herb stratum he sometimes observed 90% of infestation of *A. nemoralis*.

The first trial in controlling *A. nemoralis* with *Trichogramma* in forest surroundings was made by Kadłubowski (1961). In these experiments he obtained 42% effectiveness in the control of the pest through parasitism of eggs.

The present experiments were conducted with 20 trees on the outskirts of a high concentration center of *A. nemoralis* in the vicinity of Kamieńsko in the Łódź district. The *Trichogramma*, in test tubes covered with gauze as formerly described, were placed in the lowest whorl of the crown at the rate of 3,000 per tree. The *Trichogramma* were introduced on the 5th of May, 1960, during the time of *A. nemoralis* most intensive swarming, when its eggs were in the first and second phase of development, with only single eggs showing symptoms of being in the third stage of development. *T. cacoeciae*, reared on the eggs of *C. pomonella* and held the entire winter on *Sitotroga cerealella* eggs was introduced in the pines. Two experimental trees and four control trees were cut on the 22nd of May, 1960, in order to check the results of the experiment. The results of the observations on the *A. nemoralis* eggs are presented in summary (Tab. XXVIII).

Results from experiments in the control of *Acantholyda nemoralis* with *T. cacoeciae* in Kamieńsk in 1960

Tab. XXVIII

	Number of examined trees	Number of eggs of *A. nemoralis* found	Number of eggs attacked by *Trichogramma*	Per cent of attacked eggs
Trees with *Trichogramma*	2	1237	393	31.8
Control trees	4	2051	144	7.0

Although these experiments were not conducted on a large scale, they still allow an evaluation of the possibilities of the use of *Trichogramma* for the biological control of *A. nemoralis*. The results of the experiment (31.8% egg mortality) are encouraging only if we take into consideration the fact that the introduced *Trichogramma* (reared from the eggs of *C. pomonella* and held for the winter on *S. cerealella* eggs) was not the most appropriate material for this control experiment. In this case, the main aim was to checking the effectiveness of *T. cacoeciae* (reared from the eggs of *S. cerealella*) as regards economical advantage and not from the viewpoint of a high rate of effectiveness.

I found no morphological differences between the forest form of *Trichogramma* and that reared from the eggs of *C. pomonella*. It can be assumed that the above forms belong to one species. The occurrence of a single development cycle in the case of *Trichogramma* parasiting on the eggs of *A. nemoralis* (Koehler 1957), as well as the possibility of adaptation to the single development cycle of *Cacoecia rosana* of *T. cacoeciae* appearing in the orchard (Telenga 1959a) should be noted.

The results of experiments presented in this paper point out fairly sharp differences between the three species of *Trichogramma* known in Poland. *T. evanescens* and *T. cacoeciae* will regularly produce 7 generations in one season, while *T. embryophagum* will produce only 6. Variations in the resistance to the action of low temperatures were also found. The dormant larvae of *T. embryophagum* were found to be the most resistant, some of them (22.6%) surviving a temperature of – 30°C whereas the least resistant larvae, *T. cacoe-*

ciae, had all died in a temperature of – 30°C. The experiments on survival in winter confirmed that the dormant larvae of *T. embryophagum* and *T. evanescens* are more winter resistant than *T. cacoeciae* larvae. The survival rates were 47.7% for *T. embryophagum*, 44.4% for *T. evanescens*, and 20.6% for *T. cacoeciae*.

The vertical dispersal of the three species of *Trichogramma* was examined by noting the number of deposits and number of eggs in a deposit of *Sitotroga cerealella* eggs which were attacked in given positions by a given species. Of 46 deposits attacked by *T. evanescens*, 21 were in the lower parts of the crown. The per cent of eggs attacked in the lower parts in relation to the total number attacked was 77.3%. Infestation with *T. cacoeciae* was more uniform, although more of the infested eggs were found in the lower and center parts of the tree crown. Most of the eggs attacked by *T. embryophagum* were found in the upper and central parts of the crown. Only 0.7% of the total number attacked were in the lower parts of the crown.

These differences can be explained by the fact that *T. cacoeciae* reared from the eggs of *Tortricidae* is a species with a less positive phototaxis than *T. embryophagum* reared from the eggs of *Malacosoma neustria*. When *T. evanescens*, a field species, is introduced in a tree crown, it occupies mainly the lower parts of the crown.

The data collected on the horizontal dispersal of *Trichogramma* can not be used for accurate comparison, since the dispersal of the various species was observed in different environments. The obtained data only allow stating that the active dispersal of *T. evanescens* usually does not exceed 40 meters, and that of *T. cacoeciae* and *T. embryophagum* does not exceed 60 meters.

Differences in the reactions of the various species of *Trichogramma* to an increase in density suggest marked ecological differences among the species. *T. evanescens*, a species with a fairly wide adaptation, known to attack 120 species of insects, can with optimum density attack an average of 82% of the eggs of *S. cerealella*. In such conditions, *T. evanescens* produces more offspring than the other two species. *T. cacoeciae*, a species with a rather narrow specialization has a wide optimum density range, from 5 to 15 females for 100 *S. cerealella* eggs. With a maximum density, the per cent of attack usually does not exceed 70%.

If the critical density value is exceeded, the number of offspring rapidly decreases. *T. embryophagum* is also a narrowly specialized species, but having a narrow optimum density range (35 females for 100 *S. cerealella* eggs). The maximum degree of enfestation of *S. cerealella* eggs was 73%, similar to the corresponding figure for *T. cacoeciae*.

Using biological tests to analize the food selectivity of the three species of *Trichogramma*, distinct differences can be found (Tab. XV). The most polyphagous is *T. evanescens*, with *T. cacoeciae* and *T. embryophagum* in second and third place, respectively.

It is possible that certain general dependencies may exist not only in the case of *Trichogramma*, but also in related species. Without doubt, the density of the host's egg deposits on the degree of infestation by the parasite is of much importance when using biological control. The data from the conducted experiments clearly indicate that along with a rise in the density of the host's egg deposits there is an increase in the number of deposits and total number of eggs attacked by *Trichogramma*. In other words, there is an increase in the activity of *Trichogramma* corresponding to an increase in the number of deposits on a given area. Even in non-integrated systems, however, this is not purely a proportional relationship. The results suggest that a threshold of density for a given species should exist, above which there is an increase in the activity of the parasite. From a theoretical standpoint, it can be supposed that the activity of the parasite depends on the degree of integration of a system. A correlation was found between the number of attacked *S. cerealella* eggs and their distance from the place of introduction of the *Trichogramma*. There is a larger coefficient of correlation in fields where the egg deposits are placed every meter, in contrast to fields with a lower density of egg deposits. This means that in the case of a dense deposit distribution, the eggs near the place of the parasite's introduction are attacked most intensively, while in the case of less dense deposit distribution, all deposits within the range of the parasite's dispersal are more uniformly attacked.

When breeding parasites using the eggs of orchard and garden pests there is a high percentage of infestation by *Trichogramma* near the end of the vegetative season. In the spring, even with the most attractive eggs of *Noctuidae* collected in natural conditions, it is difficult to breed *Trichogramma*. The above data show that, in comparison to the spring population, the parasite population is very high in July, August, and during the first part of September. This hypothesis was confirmed by experiments in which natural host's eggs were placed in the orchard and the number of attacked eggs was counted. It should be noted that methods of determining number changes (which are based on placing the more or less attractive host's eggs in the orchard) can not only indicate the number of *Trichogramma* present at a given time, but also indicate the presence or absence in the orchard of a sufficient number of natural hosts.

Results based on material gathered by this method indicate that one of the main causes of the low number of *Trichogramma* during the spring is the scarcity of natural host's eggs during the period of the last autumn generations. Undoubtedly, part of the hibernating *Trichogramma* population dies as a result of other causes, one of these being low temperatures. Low winter temperatures, however, are not of paramount importance since *Trichogramma* are able to stand temperatures as low as $-35°C$; these temperatures are rare in Poland.

It is possible then, that through the introduction of an extra number of hosts we can retard the reduction of the autumn parasite population to a considerable degree. This can be done by seeding plants on which the hosts of *Trichogramma* (neutral in respect to fruit trees and with development cycles so timed that the *Trichogramma* could hibernate in their eggs) can live and multiply. There have been positive results from the first trials in decreasing the role of the host in reducing the number of parasites present in the orchard during autumn. These experiments have consisted of introducing an extra number of hosts in this period.

The use of *Trichogramma* in controlling plant pests, based on the mass breeding of *Trichogramma* in the laboratory, is increasing rapidly. Several undesirable factors (Rubcov 1951) connected with this method have been partly eliminated by lessening the differences between laboratory and natural breeding conditions, and by fairly effectively eliminating the degenerative effects of inbreeding on *Trichogramma* reared from the eggs of *S. cerealella.* Thanks to this the mass introduction of parasites, gives very satisfactory results in the biological control of tree and plant pests. This method was used in these experiments over the control of cabbage pests (*Plutella maculipennis, Pieris brassicae, P. rapae*); apple tree pests (*Carpocapsa pomonella, Laspeyresia funebrana)*; and pine tree pests (*Evetria buoliana, Acantholyda nemoralis*).

Using a single phase introduction of *T. evanescens* for the control of the second generation of *P. maculipennis*, 67% of the eggs in a field were attacked. The number of caterpillars appearing in relation to the control section was reduced 57.7%. The use of *T. evanescens* in a field of early cabbage ("Pierwszy Zbiór") brought a reduction in the number of *P. brassicae* and *P. rapae* of 73.4% and 75.5%, respectively in relation to the control plots. In the same experiments using another variety ("Amager" short stem), the number of *Pieridae* caterpillars was reduced by 81.2%.

Here, it should be noted that because of the long egg laying period characteristic of *P. maculipennis* and *Pieridae*, when using one phase introduction there will be a gap in the occurrence of the parasites from the time of introduction to the flight of the introduced parasites offspring. This applies mainly to *P. maculipennis*, and undoubtedly affects the results of a control negatively. A two phase introduction of *Trichogramma* would probably considerably decrease the number of caterpillars appearing in the field.

Promising results were also obtained using *Trichogramma* to control *C. pomonella* and *L. funebrana.* Experiments showed that with even one phase introduction of *Trichogramma*, in a location where there is a sufficiently high pest population density, the per cent of eggs attacked can be as high as 70. There need be no hesitation in using biological control in orchards where chemical control was carried out. Results of experiments conducted in 1961 show that parasites were most effective in orchards where chemicals were intensively used. In the Przegorzewice Nowe orchard (Tab. XXVI) where chemical operations had been carried out, the reduction in the amount of damaged fruit was 68.9% using the amount of damaged fruit in the control plot as comparative basis. On the other hand in the Łomna orchard where chemical operations had not been used, a reduction of only 49% was obtained. The times of introduction of the parasite and the numbers released were the same in each case.

The orchard in Łomna is a natural habitat for *Trichogramma* and those present naturally consistently reduce the number of *C. pomonella* eggs by 15–20%. The biocenotic pattern in this orchard is more stable than in the Przegorzewice Nowe orchard. Because of this, we can suppose that the introduction of parasites to a "poor" biocenosis, such as an orchard in which chemicals were used, can be carried out without any difficulty. On the other hand, when the biocenotic pattern in an area has not been disturbed for several years, the parasite-host relationship may be balanced with the result that an introduced parasite may have trouble establishing itself. In such a situation, the degree of infestation of eggs will hover close to a certain average. In this way, the lower effectiveness of biological control in orchards which have not been protected through the use of chemicals can be partly explained.

Introductory trials in the use of *T. cacoeciae* for the control of *A. nemoralis*, and especially *E. buoliana*, showed satisfactory results. There are good possibilities for such control of *E. buoliana* since it is a very attractive host as evidenced by an 80% infestation by the parasite. We still lack complete information concerning the yearly development cycle of *Trichogramma* inhabiting a forest, changes of hosts, and required wintering conditions. Because of this we can not as of yet make adequate use of *Trichogramma* in a rich forest biocenosis.

In concluding, consideration will be given to the possibilities of using *Trichogramma* for the control of *Panolis flammea*. *Trichogramma* is a most valuable biocenotic component in forests which are continuously threatened by *P. flammea*. One of the factors contributing to this is the high degree of infestation of the eggs of *P. flammea*, sometimes reaching 100%.

Other factors which make *Trichogramma* useful in controlling *P. flammea* are a long period in which the eggs are attractive (the day before the hatching of the caterpillars, a part of the eggs are still being attacked), as well as the possibility of two generations of *Trichogramma* developing in the eggs of *P. flammea*.

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BADANIA NAD BIOLOGIĄ, EKOLOGIĄ I WYKORZYSTANIEM W OCHRONIE ROŚLIN GATUNKÓW Z RODZAJU *TRICHOGRAMMA* WESTW.

Streszczenie

W pracy przedstawione są wyniki badań nad trzema gatunkami z rodzaju *Trichogramma*: *Trichogramma evanescens* Westw., *Trichogramma cacoeciae* March., i *Trichogramma embryophagum* (Htg.), należącymi do pasożytniczych błonkówek (*Hymenoptera, Chalcidoidae, Trichogrammatidae*).

1) *T. evanescens* – wyhodowany został z jaj piętnówki kapustnicy (*Barathra brassicae* L.), bielinka kapustnika (*Pieris brassicae* L.) i bielinka rzepnika (*P. rapae* L.). Jest to gatunek występujący na polach i w ogrodach. W sadach pojawia się sporadycznie.

2) *T. cacoeciae* – wyhodowany został z jaj owocówki jabłkóweczki (*Carpocapsa pomonella* L.), osnui gwiaździstej (*Acantholyda nemoralis* Thoms.), strzygoni choinówki (*Panolis flammea* Schiff.) i zwójki sosnóweczki (*Evetria buoliana* Schiff.). Jest to gatunek porażający jaja owadów, występujących głównie na drzewach.

3) *T. embryophagum* – wyhodowany został z jaj pierścienicy nadrzewki (*Malacosoma neustria* L.). Jest to pasożyt owadów występujących w sadach i lasach na terenach suchych.

W części wstępnej przedstawione są stosunki taksonomiczne w obrębie rodzaju *Trichogramma*. Wobec dużego zamieszania, jakie panuje w taksonomii rodzaju *Trichogramma* i wobec możliwych na tym tle nieporozumień uznano za konieczne ustosunkowanie się do najnowszych prac systematycznych na ten temat. Przeprowadzono krytyczną analizę tych poglądów w oparciu o wyniki badań autora.

Badając indywidualne cykle rozwojowe poszczególnych gatunków oraz liczbę pokoleń w ciągu roku, stwierdzono, że w warunkach klimatycznych Polski centralnej *T. evanescens* i *T. cacoeciae* dają do 7 pokoleń przy rocznej sumie efektywnych temperatur ponad 850. Natomiast *T. embryophagum* daje tylko 6 pokoleń (Tab. II, III, IV).

W badaniach nad wpływem niskich temperatur ustalono różnice w odporności badanych gatunków na ich działanie. Temperaturę obniżano za pomocą „suchego lodu" (zestalonego dwutlenku węgla), do pomiaru zaś używano termopar. Z obserwacji autora wynika, że najodporniejszym gatunkiem na działanie niskich temperatur jest *T. embryophagum*.

Śmiertelność diapauzujących larw *T. embryophagum* przy obniżaniu temperatury do $-30^{\circ}C$ wynosi 77,4%. W przypadku *T. evanescens* w tych samych warunkach ginie 97,9% larw. *T. cacoeciae* jest najmniej odpornym gatunkiem, gdyż przy $-30^{\circ}C$ giną wszystkie larwy (Tab. VI, VII; Fig. 1).

W części pracy obejmującej wyniki badań nad rozlotem kruszynka przedstawione są doświadczenia, związane z wpływem gęstości złóż jaj żywiciela na rozlot. Doświadczenia te wskazują na to, że wraz ze wzrostem zagęszczenia złóż jaj żywiciela, wzrasta ilość opanowanych przez pasożyta złóż i jaj w złożach. Innymi słowy, aktywność kruszynka zwiększa się wraz ze wzrostem zagęszczenia złóż jaj żywiciela, przypadających na daną powierzchnię. Uzyskane wyniki wskazują, że istnieje próg zagęszczenia, charakterystyczny dla danego gatunku, lub grupy gatunków, powyżej którego następuje wyraźny wzrost aktywności introdukowanych pasożytów (Tab. IX, Fig. 2).

Wyniki badań nad rozlotem pionowym, uzyskane na podstawie ilości porażonych złóż i jaj skośnika zbożowiaczka (*Sitotroga cerealella* Oliv.) w złożach, wskazują na daleko idące zróżnicowanie poszczególnych gatunków. *T. evanescens* poraża głównie złoża jaj wyłożone w dolnych partiach koron drzew. Rozmieszczenie porażonych przez *T. cacoeciae* złóż i jaj w złożach było bardziej równomierne, większe jednak w środkowych i górnych częściach koron drzew. Największa ilość porażonych przez *T. embryophagum* złóż i jaj w złożach znajdowała się w górnych i środkowych partiach koron drzew (Tab. XIII, XIV).

Rozlot poszczególnych gatunków był badany w różnych środowiskach, dlatego uzyskane dane trudno porównywać. Można jedynie stwierdzić, że aktywny rozlot poziomy *T. evanescens* nie przekraczał 40 m, zaś *T. cacoeciae* i *T. embryophagum* – 60 m.

W wyniku doświadczeń laboratoryjnych, nad wpływem gęstości populacji kruszynka na potomstwo pasożyta i żywiciela, stwierdzono, że wraz ze wzrostem zagęszczenia wprowadzonych imagines, ilość potomstwa pasożyta osiąga maksimum, następnie maleje, przy czym każdy gatunek posiada swoją charakterystyczną krzywą wylotu osobników potomnych.

U *T. evanescens* maksymalna ilość potomstwa pasożyta wylatuje przy zagęszczeniu 10–15 samic kruszynka na 100 jaj skośnika zbożowiaczka. U *T. cacoeciae* maksimum wylotu pasożyta jest bardzo szerokie i zawiera się w granicach od 5 do 15 samic kruszynka na 100 jaj skośnika zbożowiaczka. Największa ilość potomstwa u *T. embryophagum* przypada dopiero na zagęszczenie równe 35 samic na 100 jaj skośnika.

Z trzech badanych gatunków kruszynka najwyższy stopień polifagii wykazuje *T. evanescens*. Z 38 uwzględnionych w badaniach gatunków owadów, 28 okazało się potencjalnymi żywicielami o dużym lub średnim stopniu atrakcyjności, 8 – żywicielami o małym stopniu atrakcyjności, zaś zaledwie 2 gatunki były omijane przez *T. evanescens*. Na drugim miejscu pod tym względem znalazł się *T. cacoeciae*. Z 39 użytych jako test gatunków 26 należało do atrakcyjnych lub średnio atrakcyjnych, 11 do nieatrakcyjnych żywicieli, a 2 były omijane. *T. embryophagum* wykazał najmniejszą ilość żywicieli atrakcyjnych bo 22. Natomiast na 37 użytych jako test gatunków, aż 6 było omijanych przez imagines pasożyta (Tab. XV, XVI).

Hodowla pasożytów z jaj owadów, szkodników sadów i ogrodów, wskazuje na dość wysoki procent porażenia ich przez kruszynka pod koniec okresu wegetacyjnego. Liczebność naturalnych populacji kruszynka jest niewspółmiernie wysoka w końcu lipca, w sierpniu i na początku września, w stosunku do liczebności na wiosnę. Podobne wyniki uzyskano w badaniach nad dynamiką liczebności kruszynka przeprowadzonych przez autora metodą wykładania jaj żywicieli kruszynka w sadzie (Fig. 3, 4, 5, 6). Należy podkreślić, że metoda badania zmian liczebności kruszynka, polegająca na wykładaniu jaj, umożliwia równoczesną ocenę aktualnego nasilenia naturalnych żywicieli w sadzie. W oparciu o materiały zebrane tą metodą można przypuszczać, że jedną z głównych przyczyn niskiej liczebności kruszynka w okresie wiosennym jest brak odpowiedniej ilości jaj naturalnych żywicieli w okresie lotu ostatnich, jesiennych generacji pasożytów. Prawdopodobnie przez wprowadzenie dodatkowych żywicieli, uda nam się w znacznym stopniu zahamować redukcję populacji pasożyta w okresie jesiennym. Pierwsze próby tego rodzaju przyniosły pozytywne rezultaty.

Stosując metodę introdukcji wyhodowanych w laboratorium imagines kruszynka, przeprowadzono doświadczenia nad zwalczaniem szkodników kapusty: tantnisia krzyżowiaczka (*Plutella maculipennis* Curt.), bielinka kapustnika i bielinka rzepnika, szkodnika jabłoni – owocówki jabłkóweczki oraz szkodników sosny – zwójki sosnówki i osnui gwiaździstej.

W wyniku jednorazowego wprowadzenia *T. evanescens* w celu zwalczania drugiej generacji tantnisia krzyżowiaczka uzyskano 67% porażonych jaj szkodnika na poletku z kruszynkiem, zaś nasilenie występowania gąsienic w stosunku do części kontrolnej zostało zmniejszone o 57,7%. Zwalczanie biologiczne przy użyciu kruszynka (*T. evanescens*) na polach kapusty wczesnej odmiany „Pierwszy Zbiór", pozwoliło na zmniejszenie nasilenia występowania gąsienic bielinka kapustnika i bielinka rzepnika w porównaniu z poletkami kontrolnymi o 73,4 i 75,5%. Natomiast na kapuście „Amager" niskogłębowa nasilenie występowania gąsienic zostało zmniejszone o 81,2% (Tab. XIX, XX, XXI, XXII i XXIII).

Obiecujące wyniki otrzymano również przy zastosowaniu kruszynka do zwalczania owocówki jabłkóweczki (Tab. XXIV, XXV, XXVI). Z przeprowadzonych doświadczeń wynika, że nawet przy jednokrotnym wprowadzeniu kruszynka można otrzymać przy odpowiednim zagęszczeniu populacji szkodnika, dość wysoki stopień opanowania jaj sięgający 70%. Obawy co do kolizji zabiegów biologicznych i chemicznych w sadach, gdzie stosuje się systematycznie walkę chemiczną, zgodnie z terminarzem sadów, wydają się nieuzasadnione. Z doświadczeń przeprowadzonych w 1961 r. wynika, że właśnie w sadzie, w którym stosowano intensywną ochronę chemiczną, wprowadzone pasożyty wykazały najwyższą skuteczność. W sadzie takim (Przegorzewice Nowe) uzyskano zmniejszenie ilości uszkodzonych owoców w stosunku do części kontrolnej o 68,9%, natomiast w innym sadzie (Łomna), gdzie nie prowadzi się zabiegów chemicznych, skuteczność wyrażała się liczbą 49,2% chociaż ilość wprowadzonych pasożytów i terminy introdukcji były identyczne.

Wstępne próby zastosowania *T. cacoeciae* do zwalczania osnui gwiaździstej, a przede wszystkim zwójki sosnóweczki, należy uznać za zadowalające. Przekraczające

80% porażenie jaj zwojki sosnóweczki (Tab. XXVII) na powierzchniach doświadczalnych wskazuje niewątpliwie na dużą atrakcyjność jaj tego szkodnika dla kruszynka i na duże możliwości biologicznego zwalczania.

Efektywność kruszynka w zwalczaniu osnui gwiaździstej (Tab. XXVIII) była nieznaczna (31,8%).

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