



Biological Control and Crop Protection

Size and flight ability of *Telenomus remus* parasitoids reared on eggs of the factitious host *Corcyra cephalonica*



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ABSTRACT

In two independent bioassays, size and flight ability of parasitoids reared on eggs of *Corcyra cephalonica* for 19 generations and parasitoids reared on a natural host (*Spodoptera frugiperda* eggs) for 250 generations were compared as fast quality control procedures for insect rearing. The size of parasitoids was examined by morphometric analysis using a stereoscope. Length and width of the wings, right hind tibia, and the body of 20 individuals (males and females) were measured. In the analysis of flight ability, parasitoids were divided into three groups: individuals able to fly ("flyers"), individuals that did not fly but had no visible deformation ("walkers"), and individuals with visible deformation ("deformed"). We observed that parasitoids were larger when reared on the natural host than on the factitious host for all evaluated morphological characters. However, there was no significant difference between the treatments regarding the number of "flyers", "walkers" or "deformed" parasitoids. This indicates that even though the rearing of *T. remus* on a factitious host affects parasitoid size, it does not necessarily affect its flight ability and therefore suggests that *C. cephalonica* is suitable as a factitious host for mass rearing of *T. remus*. Other biological parameters still need to be evaluated, such as host finding ability, parasitism capacity, and parasitoid field efficacy in order to provide a more complete picture of the effects caused by a host change. However, because fast laboratory tests are needed in rearing facilities, the one used in this study might be useful to rapidly assess parasitoid quality.

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Introduction

Telenomus remus (Nixon, 1937) (Hymenoptera, Platygastridae) is an egg parasitoid of various Lepidoptera species (Cave, 2000, Pomari et al., 2012), currently only reared on a small scale due to the inherent difficulties of rearing it on its natural host, *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera, Noctuidae) (Pomari-Fernandes et al., 2014). *Spodoptera frugiperda* rearing is too time- and resource-consuming (Perkins, 1979), mainly because of larval cannibalism, which requires the rearing of larvae in individual vials to decrease pre-imaginal mortality (Chapman et al., 2000). A possible alternative is rearing the parasitoid on a factitious host. Natural enemy rearing on factitious hosts is a determining factor for the success of many biological control programs because it reduces production costs and increases the viability for the large-scale use of the biocontrol agent (Parra, 1997).

It is crucial that laboratory-reared insects remain capable of controlling target pests in the field similar to biological control agents found in nature (Clarke and McKenzie, 1992). This has been one of the main goals of insect-rearing facilities that were created to supply biological control programs with natural enemies of target pests. Therefore, quality control of the produced insect is a key factor for the success of most biological control programs, with the overall quality of the natural enemy defined as its ability to control target pests after its release in the field (Clarke and McKenzie, 1992). However, field evaluation can be expensive and ineffective if it is not clearly defined. Thus, fast and easy-to-perform laboratory tests are of theoretical and practical interest. They can give an indication of field performance and probably make a more labor-intensive field evaluation unnecessary. For example, in order to improve rearing of the egg parasitoid *Trichogramma pretiosum* Riley, 1879 (Hymenoptera: Trichogrammatidae), the International Organization of Biological Control (IOBC Global Working Group: Quality Control of Mass Reared Arthropods) recommends the evaluation of seven different biological variables in the laboratory (van Lenteren, 2003). However, Prezotti (2001) reported that only the

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variables longevity, parasitism index, and flight activity need to be assessed to maintain the high quality standards required for mass rearing of this egg parasitoid.

Flying and walking are important characteristics for a natural enemy's performance under field conditions since they are directly related to its foraging and dispersal capacity (Gardner and Lenteren, 1986). It is important to point out that the values of these traits may change across generations during mass rearing, and therefore should be closely monitored. Thus, to ensure the quality of laboratory-produced parasitoids, it is important to develop methods that assess the ability of parasitoids to fly and walk.

In addition, insect morphology must be considered, which may be influenced by environmental variation and host changes (Grenier et al., 2001). Parasitoid size is a morphological parameter that might be impaired by host choice. Therefore, this study aimed to evaluate the size and flight ability of *T. remus* reared on eggs of the factitious host *Corcyra cephalonica* (Stainton, 1866) (Lepidoptera: Pyralidae) compared to those reared on eggs of the natural host *S. frugiperda* in order to determine differences between those parasitoids. This research generated information that will help to improve the quality control of future *T. remus* mass production in the laboratory as well as the use of this egg parasitoid in extensive biocontrol programs.

Material and methods

Parasitoid and host colonies

Corcyra cephalonica eggs, *S. frugiperda* eggs and *T. remus* females used in the experiments came from insect colonies kept at Embrapa Soybean, Londrina, State of Paraná, Brazil. *Spodoptera frugiperda* was originally collected from maize plants in Rio Verde, State of Goiás, and has been kept in the laboratory for approximately five years. This species is reared under laboratory-controlled environmental conditions ($25 \pm 2^\circ\text{C}$ temperature, $70 \pm 10\%$ relative humidity, and 14/10 h photoperiod [L/D]) and fed on the artificial diet described by Greene et al. (1976) and Parra (2001). *Corcyra cephalonica* was supplied by UNESP/Jaboticabal and has been kept in the laboratory for approximately three years. *Corcyra cephalonica* is reared on its natural diet, using a methodology adapted from Zeller (1879) for rearing *Anagasta kuehniella* (Lepidoptera: Pyralidae) (Parra, 1997).

Telenomus remus was originally collected in Ecuador and reared at the parasitoid rearing facilities of ESALQ/USP (Luiz de Queiroz College of Agriculture/University of São Paulo), from where some specimens were transferred to Embrapa Soybean seven years (around 250 generations) ago. At Embrapa Soybean laboratory, *T. remus* was reared on both *S. frugiperda* egg masses and on unviable *C. cephalonica* (up to 24 h) eggs in order to provide two distinct colonies (reared on different hosts). In each colony, host eggs were glued onto white Bristol board ($2.5\text{ cm} \times 5\text{ cm}$) and placed with eggs previously parasitized by *T. remus*. Small drops of honey were added to the inside of these tubes to feed the adults as soon as they emerged. The tubes were then closed, and the eggs were allowed to be parasitized for 24 h. The adults that emerged from these eggs were used for trials or colony maintenance.

Morphological characters of *Telenomus remus*

The experiment was carried out in a 5×2 factorial randomized block design (5 parasitoids \times 2 parasitoid genders – female or male) with 10 replicates consisting of one adult that was measured individually. Therefore, 10 male and 10 female parasitoids reared on *C. cephalonica* eggs from four different generations (F_1 , F_8 , F_{13} , and F_{19}) were analyzed and compared with parasitoids reared on *S. frugiperda*. *Telenomus remus* reared on *S. frugiperda* eggs and

exposed to parasitism on *C. cephalonica* eggs formed the F_0 generation. The F_1 generation was the first generation of parasitoids reared on *C. cephalonica* eggs, and successively afterwards.

For each replicate (adult insect), morphometric evaluations of length and width of the right anterior wing, length of the right hind tibia, and body length (head to the tip of the abdomen) were performed. To measure morphological characters, each specimen was photographed in a stereoscopic microscope (Leica Application Suite, Version 1.6.0). Images were used for morphometric analysis with the software Image J (Version 1.47).

Flight ability of *Telenomus remus*

The trial was carried out in controlled environmental conditions inside a Biochemical Oxygen Demand (BOD) climate chamber (ELETROLab®, model EL 212, São Paulo, SP, Brazil) set at $70 \pm 10\%$ humidity, temperature of $25 \pm 2^\circ\text{C}$, and 12/12 h photoperiod (L/D). Experimental design was completely randomized with 5 treatments (*T. remus* from *C. cephalonica* eggs of the F_1 , F_8 , F_{13} , and F_{19} generations and *T. remus* from eggs of the natural host, *S. frugiperda*) and 10 replicates. Each replicate contained 100–150 pupae of *T. remus* reared on *C. cephalonica* (F_1 , F_8 , F_{13} , and F_{19}) or *S. frugiperda* eggs. Around the time of emergence, those *T. remus* pupae were put on a plastic plate of 2.5 cm diameter and 1 cm height, which was placed on the bottom of each replicate. This protocol was originally proposed by Dutton and Bigler (1995) and adapted in ESALQ-USP (Prezotti et al., 2002), as briefly described in the following.

Replicates consisted of a cage made of a PVC cylinder (18 cm high and 11 cm in diameter). The interior of the cage was painted with black ink on a white acrylic latex layer to facilitate attachment. The bottom of the cage was sealed with flexible black plastic (larger than the tube diameter) fitted tightly by a Styrofoam disk approximately one centimeter thick and of the same diameter as the tube. After fitting, the protruding portion of the plastic was fixed to the tube by elastic bands, creating a perfect seal and preventing the escape of parasitoids. Then, entomological adhesive (composed of polybutene and synthetic silica) was spread over the walls of the cage (3.5 cm from the bottom), to serve as a trap for “walkers” (parasitoids that were unable to fly but could walk and had no visible deformation). A transparent Petri dish sprayed with entomological adhesive was placed on top of the cylinder to serve as a trap for flying parasitoids.

The position and the number of parasitoids in the adhesive ring (“walkers”), in the Petri dish (“flyers”), and “deformed” were recorded and used to calculate their percentages of the total number of emerged adults. The parasitoids considered “non-flyers” were observed under a stereoscope to determine the percentage of individuals with wing deformities (“deformed”) (Prezotti et al., 2002).

Data analyses

Prior to ANOVA, experimental results were subjected to exploratory analyses to assess the assumptions of normality of residuals (Shapiro and Wilk, 1965) and homogeneity of variance of the treatments (Burr and Foster, 1972) and, if necessary, transformed for ANOVA. For “Deformed” parasitoids, data was transformed by $\sqrt{X + 0.5}$. The treatment means were then compared by the Tukey test at the 5% probability level (SAS Institute, 2001).

Results

Morphological characters of *Telenomus remus*

There was no interaction between parasitoids and gender in the factorial analyses (Table 1), and therefore both factors were

Table 1

Telenomus remus: measurements of morphological characters (mm) when reared on the eggs of the natural host (*Spodoptera frugiperda*) and the factitious host (*Corcyra cephalonica*).

Parameter	Morphological characters (cm) ^a			
	Wing length	Wing width	Body length	Right hind length
<i>Parasitoid</i>				
<i>S. frugiperda</i> ^b	0.546 ± 0.008 a	0.176 ± 0.003 a	0.601 ± 0.013 a	0.152 ± 0.004 a
<i>C. cephalonica</i> ^c F ₁	0.485 ± 0.007 b	0.152 ± 0.003 b	0.551 ± 0.008 b	0.132 ± 0.003 c
<i>C. cephalonica</i> F ₈	0.490 ± 0.006 b	0.157 ± 0.003 b	0.584 ± 0.010 ab	0.146 ± 0.003 ab
<i>C. cephalonica</i> F ₁₃	0.487 ± 0.007 b	0.149 ± 0.003 b	0.567 ± 0.012 ab	0.131 ± 0.003 c
<i>C. cephalonica</i> F ₁₉	0.476 ± 0.007 b	0.151 ± 0.002 b	0.570 ± 0.010 ab	0.140 ± 0.003 bc
<i>Gender</i>				
Female	0.483 ± 0.005 B	0.155 ± 0.002 ^{ns}	0.601 ± 0.007 A	0.132 ± 0.002 B
Male	0.510 ± 0.006 A	0.159 ± 0.002	0.547 ± 0.005 B	0.149 ± 0.002 A
<i>Statistics</i>				
CV (%)	5.81	8.17	6.80	8.18
F _{host/generation}	18.85	14.13	4.71	12.61
F _{gender}	21.41	2.98	48.95	54.01
F _{host/generation*gender}	0.10	0.19	0.60	1.35
P _{host/generation}	<0.0001	<0.0001	0.0018	<0.0001
P _{gender}	<0.0001	0.0881	<0.0001	<0.0001
P _{host/generation*gender}	0.9829	0.9408	0.6624	0.2599

^a Means (±SE) followed by the same lower case letter in host/generation and capital letters in gender parameters did not statistically differ (Tukey test, $p > 0.05$) for each morphological character.

^b *T. remus* reared on eggs of *S. frugiperda* by approximately 250 generations.

^c *T. remus* reared on eggs of *C. cephalonica* by 1 (F₁), 8 (F₈), 13 (F₁₃), and 19 (F₁₉) generations.

^{ns} Non-significant.

analyzed independently. In the parasitoids analysis, differences were observed in all evaluated morphological characters: wing length, wing width, body length, and right hind tibia length (Table 1). Overall, morphological measurements (mm) of *T. remus* had higher values when the parasitoid was reared on the natural host, *S. frugiperda*. Wing length and width values were significantly higher of *T. remus* reared on *S. frugiperda* than of parasitoids reared on *C. cephalonica* eggs (F₁, F₈, F₁₃, and F₁₉ generations). Body length did not differ between parasitoids reared on eggs of *S. frugiperda* or *C. cephalonica* F₈, F₁₃, and F₁₉. Also, the right hind tibia length was similar between parasitoids from *S. frugiperda* and *C. cephalonica* F₈ (Table 1). In the analysis of the factor gender, males had longer wings and tibiae than females but shorter body length. In contrast, wing width did not differ between the genders (Table 1).

Flight ability of *Telenomus remus*

The total number of parasitoids emerging from the 100 to 150 *T. remus* pupae was similar for the two hosts, varying from 114.8 (*C. cephalonica* F₁) to 127.6 (*S. frugiperda*) (Table 2). The number of *T. remus* “flyers” reared on *S. frugiperda* eggs (102.8) did not differ from

that of parasitoids reared on *C. cephalonica* eggs in the F₁ (96.8), F₈ (96.4), F₁₃ (101.9), and F₁₉ (106.3) generations (between 80.33% and 84.43% “flyers”, Table 2). Likewise, the number of parasitoids without any visible deformation that did not fly (“walkers”) were similar between treatments. In addition, “deformed” parasitoids were less than 1% in each treatment, and did not differ between treatments (Table 2).

Discussion

The observed reduction in morphological characters of *T. remus* when switching from egg of a natural to those of a factitious host might be associated with the different forms and sizes of both host eggs. Moreover, different host eggs might have different surfaces, chorion structures, and other egg properties during embryonic development (Cônoli et al., 1999). Those host features were previously pointed out as important factors for *T. remus* parasitism and development by Bueno et al. (2014). There is an important difference in shape between eggs of *C. cephalonica*, which are ellipsoidal (mean length 573.5 mm and mean width 346.1 mm) and eggs of *S. frugiperda*, which are almost spherical (mean length 454.9 mm

Table 2

Telenomus remus: flight ability (mean ± SE number of parasitoids emerged from different hosts).

Host	G ^a	Total parasitoids ^b	Flyers ^c	Walkers ^d	Deformed ^{e,f}
<i>S. frugiperda</i>	*	127.6 ± 3.9 ^{ns}	102.8 ± 2.7 ^{ns} (80.83%)	23.9 ± 2.4 ^{ns} (18.49%)	0.9 ± 0.2 ^{ns} (0.68%)
<i>C. cephalonica</i>	F ₁	114.8 ± 4.2	96.8 ± 3.4 (84.43%)	17.3 ± 1.8 (14.92%)	0.7 ± 0.2 (0.64%)
<i>C. cephalonica</i>	F ₈	116.4 ± 2.0	96.4 ± 1.9 (82.89%)	19.7 ± 1.7 (16.86%)	0.3 ± 0.2 (0.25%)
<i>C. cephalonica</i>	F ₁₃	122.7 ± 4.2	101.9 ± 3.0 (83.33%)	20.2 ± 2.7 (16.17%)	0.6 ± 0.3 (0.50%)
<i>C. cephalonica</i>	F ₁₉	126.9 ± 2.4	106.3 ± 2.3 (83.84%)	20.0 ± 1.9 (15.70%)	0.6 ± 0.2 (0.47%)
CV (%)		9.03	8.39	17.68	21.38
F		2.87	2.47	1.09	0.98
p		0.0336	0.0578	0.3753	0.4261

^a Generation of parasitoids used in the treatment (**T. remus* was reared on eggs of *S. frugiperda* for approximately 250 generations and on eggs of *C. cephalonica* for 1 (F₁), 8 (F₈), 13 (F₁₃), and 19 (F₁₉) generations).

^b Total number of parasitoids emerged in the treatment (Flyer + Walkers + Deformed).

^c Number of parasitoids able to fly, and its proportion (%) of the total number of parasitoids emerged.

^d Number of parasitoids that did not fly but had no visible deformation, and its proportion (%) of the total number of parasitoids emerged.

^e Number of parasitoids with visible deformation, and its proportion (%) of the total number of parasitoids emerged.

^f Statistics performed on transformed data by $\sqrt{X + 0.5}$.

^{ns} Non-significant.

and mean width 390.2 mm) (Cônoli et al., 1999). Host size is reported to be directly related to parasitoid dimensions (Gautum, 1986). For example, adults of *T. remus*, reared on *Agrotis spinifera* (Hubner, 1808) (Lepidoptera: Noctuidae) eggs were larger than parasitoids from *Spodoptera litura* (Fabricius, 1775) (Lepidoptera: Noctuidae) eggs, which are smaller. However, both *C. cephalonica* and *S. frugiperda* eggs have a similar volume of around 0.036 mm³ (Cônoli et al., 1999). This indicates that the host influence on the morphology of the produced parasitoids is not due to egg size alone.

For example, different time spans of co-evolution between *T. remus* and its various hosts may have resulted in different degrees of adaptation to each specific host egg (Bueno et al., 2009). The studied *T. remus* colony has been reared on *S. frugiperda* eggs under laboratory conditions for about 250 generations, possibly leading to better adaptation of the parasitoid strain to this host compared with *C. cephalonica*, which was reared for only 19 generations. As a consequence, memory of the original host may be involved in host-locating ability and host acceptance and therefore may have influenced the results reported here. However, it is important to point out that parasitoids display interspecific variation in learning rate and memory dynamics that reflects variation in the foraging task and largely determines their fitness (Hoedjes et al., 2011). Host preference innate to the species (pre-imaginal conditioning) might be altered by learning rate and memory dynamics as a result of experience gained during foraging and parasitism (Pomari-Fernandes et al., 2015). Although learning is usually considered as more important for generalists, it is also a crucial factor for specialist parasitoid wasps (Hoedjes et al., 2011) such as *T. remus*.

Parasitoids can change their innate preferences for odor cues that guide them to patches of hosts (Hoedjes et al., 2011). Associating the signs learned during parasitism or during development enables parasitoid females to locate and parasitize its host with greater efficiency and speed (Cobert, 1985; Nurindah et al., 1999; Hoedjes et al., 2011), a phenomenon known as α -conditioning or associative learning (Vinson, 1998; Nurindah et al., 1999). Therefore, although female parasitoids have an innate preference for certain odors, foraging efficiency of most species is optimized by associative learning (Hoedjes et al., 2011). Parasitoids which had experienced the presence of a certain host species, thereafter narrow their (olfactory) 'search image' by learning, as a form of temporal specialization (Hoedjes et al., 2011).

In addition, morphological characters are listed in the literature as good indicators of the fitness and fertility of adult parasitoids from different hosts and rearing facilities. Changing host species can clearly impact parasitoid morphology, as reported for different species of the genus *Trichogramma* (Kazmer and Luck, 1991; Grenier et al., 2001). Differences among hosts can be due to various reasons. For example, *S. frugiperda* lays its eggs in superposed masses while *C. cephalonica* lays its eggs individually. This can affect not only parasitism but also the host's suitability for parasitoid development (Cônoli et al., 1999), directly affecting the quality of the produced parasitoids. Therefore, to study these differences in order to determine an appropriate host for parasitoid mass rearing that maximizes production, reduces costs, and does not change the morphological characters of natural enemies might be important for the success of a biological control program (Vaz et al., 2004).

Even though individuals of *T. remus* reared on *C. cephalonica* were smaller (mainly in their wing dimensions) than individuals reared on *S. frugiperda* eggs, no impairment in flying capacity was observed in the laboratory test (short distance). The similarity in the percentages of flying individuals from *C. cephalonica* (generations F₁, F₈, F₁₃, and F₁₉) and individuals from the natural host *S. frugiperda* indicates that while the reduction in wing size was significant, it was not sufficient to compromise the flight ability of the insect. The average percentage ($\approx 83\%$) of parasitoids captured

on the cover ("flyers") was similar to that found by other authors using the same protocol for other parasitoid species. Rodrigues et al. (2009) found averages from 85.9 to 97.7% of flying individuals and Prezotti et al. (2002) reported mean percentages between 74.7 and 90.6% for *T. pretiosum*. The similarity of results suggests that the protocol tested can also be used to study the flight activity of *T. remus* for quality control in mass rearing facilities.

The average percentage of "walkers" caught in the glue ring ($\approx 16\%$) was higher than that obtained in other studies using *T. pretiosum* (Prezotti et al., 2002; Rodrigues et al., 2009), which is probably related to behavioral differences between species. The percentage of these individuals with deformities such as stunted or folded wings was less than 1%. This confirms that the visual observation of the percentage of individuals with deformed wings alone is insufficient to characterize the quality of the parasitoid, since almost all of the "walkers" apparently had normal wings (Prezotti et al., 2002). These non-flying individuals should be better evaluated before determining whether they could have a negative effect on biological control programs. Gardner and Lenteren (1986) considered that both flying and walking are important features for the performance of natural enemies in field conditions, as they relate to foraging and dispersal.

Considering both the morphometry and the flight test, our results suggest that the host-specific size differences of *T. remus* especially regarding wing length and width, did not necessarily affect the flight activity of the parasitoid since the percentage of "flyers" did not significantly differ between hosts. In the future, the most appropriate number of insects to be released should be studied, based on the parasitism capacity of *T. remus*, in order to test the hypothesis that releasing a greater number of *T. remus* reared on *C. cephalonica* will be as effective as releasing a smaller number of the same parasitoid reared on *S. frugiperda*.

Other biological characteristics may also be affected due to changes in parasitoid size. For example, in nature it is common to find increasing fertility with increasing adult size. Chau and Mackauer (2001) reported that the parasitoid *Monoctonus paulensis* (Ashmead) (Hymenoptera: Braconidae) preferred larger aphids, which was understood as a process of selection to maximize their fertility (number, size, and quality of eggs). In addition, the quality of the host is not simply related to size, reflecting the biomass available to be consumed by the parasitoid, but also to the development period. To maximize its size in low-quality hosts, the parasitoid can reduce its growth rate and increase the development period (Sequeira and Mackauer, 1992). Adult parasitoids can also increase their lifespan during the absence of suitable hosts (Carneiro et al., 2009) or even develop mechanisms of oocyte absorption to physiologically synchronize egg formation with host availability (Chabi-Olaye et al., 2001). Therefore, other biological parameters still need to be evaluated such as parasitoid finding ability, parasitism capacity, and parasitoid field efficacy in order to have a more complete picture of host change effects on parasitoid biology. However, fast laboratory tests are needed in rearing facilities and the one used in this study might be useful to rapidly indicate parasitoid quality. In addition, taking into consideration the results discussed here, there is a clear indication that *C. cephalonica* can be used as a factitious host for mass rearing of *T. remus*.

Conflicts of interest

The authors declare no conflicts of interest.

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