

Parasitism capacity of *Telenomus remus* and *Trichogramma pretiosum* on eggs of moth pests of peanut

José Ricardo Lima PINTO, Odair Aparecido FERNANDES

School of Agricultural and Veterinarian Sciences, São Paulo State University (UNESP), Jaboticabal, SP, Brazil

Abstract

Telenomus remus Nixon (Hymenoptera Scelionidae) and *Trichogramma pretiosum* Riley (Hymenoptera Trichogrammatidae) are widely used for the control of lepidopteran pests in several countries, but applied programs using these parasitoids in peanuts are still rare. Therefore, the comparative parasitism capacity of *T. remus* and *T. pretiosum* in *Stegasta bosqueella* (Chambers) (Lepidoptera Gelechiidae), *Spodoptera cosmioides* (Walker) and *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera Noctuidae) eggs were studied under controlled conditions (12L:12D photoperiod, 25 ± 1 °C, and $70 \pm 10\%$ RH). Eggs of *S. bosqueella*, *S. cosmioides* and *S. frugiperda* were offered daily throughout the adult lifespan of the parasitoids. Both parasitoids did not parasitize eggs of *S. bosqueella*. Eggs of *Spodoptera* spp. were significantly more parasitized by *T. remus* than by *T. pretiosum*. These two parasitoids presented the highest parasitism rate in the first 24 hours in *Spodoptera* eggs. However, to obtain 80% of parasitism in *Spodoptera* spp. took up to seven days for *T. remus* and up to three days for *T. pretiosum*. *Telenomus remus* demonstrated a longer lifespan, greater number of emerged parasitoids, and a female-biased sexual ratio, which might result in a greater potential control of *Spodoptera* spp. in the field. For *S. bosqueella*, other biological control agents should be considered.

Key words: biological control, egg parasitoids, biological parameters.

Introduction

Technological innovations in the Brazilian peanut (*Arachis hypogaea* L.) production chain, such as the use of runner varieties, have provided an increase in planted area, yield and exports in recent years (MDIC, 2018). This leguminous plant is the main species used in crop rotation with sugarcane in the Brazilian Southeastern region, which is responsible for about 90% of the national peanut production (CONAB, 2018).

The rednecked peanutworm moth, *Stegasta bosqueella* (Chambers) (Lepidoptera Gelechiidae), and the armyworms *Spodoptera cosmioides* (Walker) and *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera Noctuidae), are reported as the main lepidopteran insects in peanut crop and may cause high yield losses (Campos *et al.*, 2010; Boiça Junior *et al.*, 2011; 2013). These insects can cause intense defoliation with negative effect on plant development. In addition, *S. bosqueella* can feed directly on the tips of peanut vines reducing their growth and, hence, peanut production in runner varieties. These insects are usually controlled by chemical insecticides, and growers do not apply other tools to control these defoliators.

Parasitoids have been used worldwide in applied biological control programs and many successful cases concern the control of insect pests (van Lenteren *et al.*, 2018). In Brazil, successful biological control by egg parasitoids in various crops, such as sugarcane, soybeans, maize, and tomato have already been reported (Parra, 2014), constituting an economically viable control method and less harmful to the environment (Simionato *et al.*, 2014). However, research on biological control of pests in peanuts is still scarce and biocontrol is not yet applied in the field.

According to Faria *et al.* (2000) for biological pest control to be successful, basic studies to evaluate biological parameters are crucial, as they are the basis for choosing the ideal control agent and assuring efficacy in a biological control program. Parasitoids of the genera *Telenomus* (Hymenoptera Scelionidae) and *Trichogramma* (Hymenoptera Trichogrammatidae) are widely used to control lepidopteran pests, mainly because these parasitoids of eggs eliminate the pest before the damage is caused to the crop (Cônoli *et al.*, 2010). Thus, considering the importance of lepidopteran pests and lack of studies on the use of egg parasitoids as biological control agents in peanuts, this work aimed to evaluate the comparative parasitism capacity of *Telenomus remus* Nixon and *Trichogramma pretiosum* Riley on eggs of *S. bosqueella*, *S. cosmioides*, and *S. frugiperda* under laboratory conditions.

Materials and methods

Host and parasitoid rearing

T. remus adults were from a strain introduced from Venezuela and kept in mass rearing using eggs of *S. frugiperda* as host, according to methodology of Bueno *et al.* (2010b). The initial colony of *T. remus* was established from 650.000 individuals collected in *S. frugiperda* egg masses in maize crop from Barquisimeto, Lara, Venezuela and introduced into Brazil in 2012 (Naranjo-Guevara *et al.*, 2020). The adults of *T. pretiosum* came from Bug Biological Agents, Piracicaba, SP, Brazil (currently Koppert Brazil - Biological Products), where they are kept on the factitious host, *Ephestia kuehniella* Zeller (Lepidoptera Pyralidae). A total of 20.000 parasitized eggs of *E. kuehniella* were provided by the company and adults of *T. pretiosum* were used in

the essays after emergence. Both parasitoids were kept in glass tubes (10 × 2 cm in diameter) and conditioned in climate chambers 12L:12D photoperiod, 25 ± 1 °C, and 70 ± 10% RH.

Adults of *S. bosqueella* were collected in a pesticide-free peanut field, brought to the laboratory and kept in acrylic cages (30 × 30 × 30 cm) inside climate chambers 12H:12D photoperiod, 25 ± 1 °C, and 70 ± 10% RH, according to Boiça Junior *et al.* (2011). The adults were fed with a 10% honey aqueous solution supplied in cotton swabs placed in the cages. Each cage had also one plastic cup (700 ml) containing one fifteen-day-after-emergence peanut seedling (*A. hypogaea* variety ‘Grano-leico’) as an oviposition substrate, which was replaced daily throughout the lifespan of adult moths. The plant parts containing eggs were clipped and transferred to plastic Petri dishes (1.5 × 9 cm in diameter). These plant fragments were placed on double-sheet moist filter paper to avoid egg viability reduction and favour initial larval development. For the studies, F2 generation eggs were used.

Adults of *S. cosmioides* and *S. frugiperda* were obtained from laboratory colonies maintained at the UNESP campus of Jaboticabal, SP, Brazil. Larvae were fed an artificial diet based on beans and wheat germ (Greene *et al.*, 1976). The adults were maintained in polyvinyl chloride (PVC) cages (21.5 × 10 cm in diameter), adopting a methodology proposed for rearing *S. frugiperda* (Bueno *et al.*, 2010b). Rearing conditions, including a potted 15-day-old peanut plant, were similar to *S. bosqueella*. Eggs laid on leaves were used for the tests.

Parasitism capacity

Freshly-laid individual eggs or egg masses (<24 hours) of the lepidopteran pests were removed along with the substrate (leaves or petioles) according to Faria *et al.* (2000). Prior to use, the eggs were counted using a stereomicroscope (Zeiss Stemi SV6, Jena, Germany) and the substrates fixed to a rectangular white cardboard (0.8 × 5 cm) using non-toxic white glue (Tenax Henkel Ltd., São Paulo, SP, Brazil). Each cardboard contained eggs of only one species: 20 eggs of *S. bosqueella*, 100 eggs of *S. cosmioides* and 100 eggs of *S. frugiperda*. Lower numbers of *S. bosqueella* eggs were offered because of limited availability. As *Spodoptera* species lay egg masses with several layers, all eggs of the upper layers were removed with a thin camel-hair brush to keep only one layer. This assured access to the host by both parasitoid species because *T. pretiosum* is not able to parasitize eggs in the lower layers of an egg mass (Carneiro and Fernandes, 2012) differently from *T. remus*. Therefore, such a strategy was adopted to reduce bias in the results.

Individual cardboards containing the eggs of one host species were inserted into flat bottom glass tubes (10 × 2 cm in diameter). One previously mated female of *T. remus* or *T. pretiosum* (<24 hours), but with no oviposition experience, was transferred into each tube as suggested by Bueno *et al.* (2010b). Honey droplets were placed into the inner wall of these tubes to provide food

to the parasitoids. Only five tubes (replicates) could be used for each parasitoid and lepidopteran species, because the number of eggs available on daily basis from *S. bosqueella* was a limiting factor. This species is not reared in artificial diet and oviposition was not enough for a larger number of replications. The tubes were closed with clear plastic film (PVC). The cardboards were replaced daily until the females died. The cardboards were transferred to similar glass tubes and maintained at the controlled conditions as mentioned below until the emergence of the parasitoids. After the emergence, all parasitoids were counted and sexed using morphological characteristics (antennae and hind tibiae), as suggested by Cave (2000) for *T. remus* and by Pinto *et al.* (1997) for *T. pretiosum*.

The experiment was carried out under controlled conditions using climate chambers 12L:12D photoperiod, 25 ± 1 °C, and 70 ± 10% RH. Longevity of experimental female parasitoids, number of eggs parasitized daily, total number of eggs parasitized per female, cumulative percentage of parasitism (total number of parasitized eggs/total number of eggs exposed to a female during its lifespan), survivorship rates of the experimental females, number of emerged parasitoids and sex ratio (number of females divided by total number of individuals) were determined.

Ultrastructure of the lepidopteran eggs

Eggs were transferred to 0.5-ml plastic microcentrifuge tubes (Eppendorf, Hauppauge, NY, USA) containing sodium phosphate buffer solution (0.1M, pH 7.2) where they were kept for 30 minutes. The eggs were then fixed in 2.5% glutaraldehyde solution in phosphate buffer (0.1M, pH 7.2) at 4 °C for 72 hours. After this period, the samples were washed using phosphate buffer solution and the material was subjected to a second fixation using 1% osmium tetroxide solution overnight at 4 °C. The samples were repeatedly washed with sodium phosphate buffer and the dehydration of the material in an increasing series of ethanol concentrations (30, 50, 70, 80, 90 and 100%) for 15 minutes each. The dehydrated material was critically dried (EMS-850) and then the stubs were prepared for gold metallization of the sample in DESK II Vacuum. Eggs were then scanned using Scanning Electronic Microscopy (model Zeiss Evo MA10, Jena, Germany).

Data analysis

Longevity, number of parasitized eggs, number of adults emerged and sex ratio were subjected to normality of the residues and homogeneity of the variance of the treatments and means were compared using the Tukey test (P = 0.05). The effect of host species, parasitoids and their interaction on the above mentioned parameters were evaluated using the F test (P = 0.05). All data were analysed using mixed models (PROC MIXED, SAS Institute, 2015). Survivorship rates of the experimental females was compared by the Kaplan-Meier Log-Rank test using PROC LIFETEST (SAS Institute, 2015).

Results

Parasitism capacity

No parasitism by *T. remus* and *T. pretiosum* on *S. bosqueella* eggs was observed. However, both parasitoids parasitized eggs of *S. cosmioidea* and *S. frugiperda*. Number of eggs parasitized was higher for *T. remus* than for *T. pretiosum* (figure 1). Cumulative percentage of parasitism attained 100% for *T. pretiosum* in less than half the time for *T. remus*.

The average number of eggs laid per female per day decreased according to the age of females (figure 1). During the first 24 hours, *T. remus* females parasitized 91.8 ± 2.8 and 90.0 ± 9.3 eggs of *S. cosmioidea* and *S. frugiperda*, respectively. On the other hand, *T. pretiosum* parasitized 33.4 ± 4.2 and 38.0 ± 8.7 eggs in the same period. Thus, *T. remus* parasitized over 2-fold (2.4 to 2.7) more eggs than *T. pretiosum* on the first day.

Females of *T. remus* and *T. pretiosum* were able to parasitize 642.0 ± 3.7 and 108.6 ± 6.2 eggs, respectively, of *S. cosmioidea* and 574.0 ± 8.0 and 121.3 ± 5.0 eggs, respectively, of *S. frugiperda* during adulthood (figure 1).

T. remus reached 80% of accumulated parasitism in *S. cosmioidea* and *S. frugiperda* eggs at ≈ 7 days. On the other hand, *T. pretiosum* required only three days to reach the same percentage of parasitism (figure 1).

The mean number of eggs laid per female per day by *T. remus* was significantly higher ($F_{3,16} = 21.49$, $P = 0.0003$) than that observed for *T. pretiosum*. On average, *T. remus* parasitized 59.2 ± 9.4 and 58.5 ± 9.5 eggs, respectively, of *S. cosmioidea* and *S. frugiperda* daily. These values were not significantly different ($F_{3,16} = 7.18$, $P = 0.9999$). There was also no significant difference in the number of eggs parasitized by *T. pretiosum* on *S. cosmioidea* (20.9 ± 7.2 eggs) and *S. frugiperda* per day (23.5 ± 4.5 eggs) ($F_{3,16} = 44.98$, $P = 0.9957$).

The emergence of *T. remus* was significantly higher than that of *T. pretiosum* ($F_{3,16} = 22.03$; $P = 0.0002$). The mean number of *T. remus* individuals emerged from daily oviposition events was 16.6 ± 2.2 and 22.7 ± 6.8 from *S. cosmioidea* and *S. frugiperda* eggs, respectively, whereas *T. pretiosum* emergence from daily oviposition events was 3.2 ± 1.2 and 1.9 ± 0.7 from *S. cosmioidea* and *S. frugiperda* eggs, respectively.

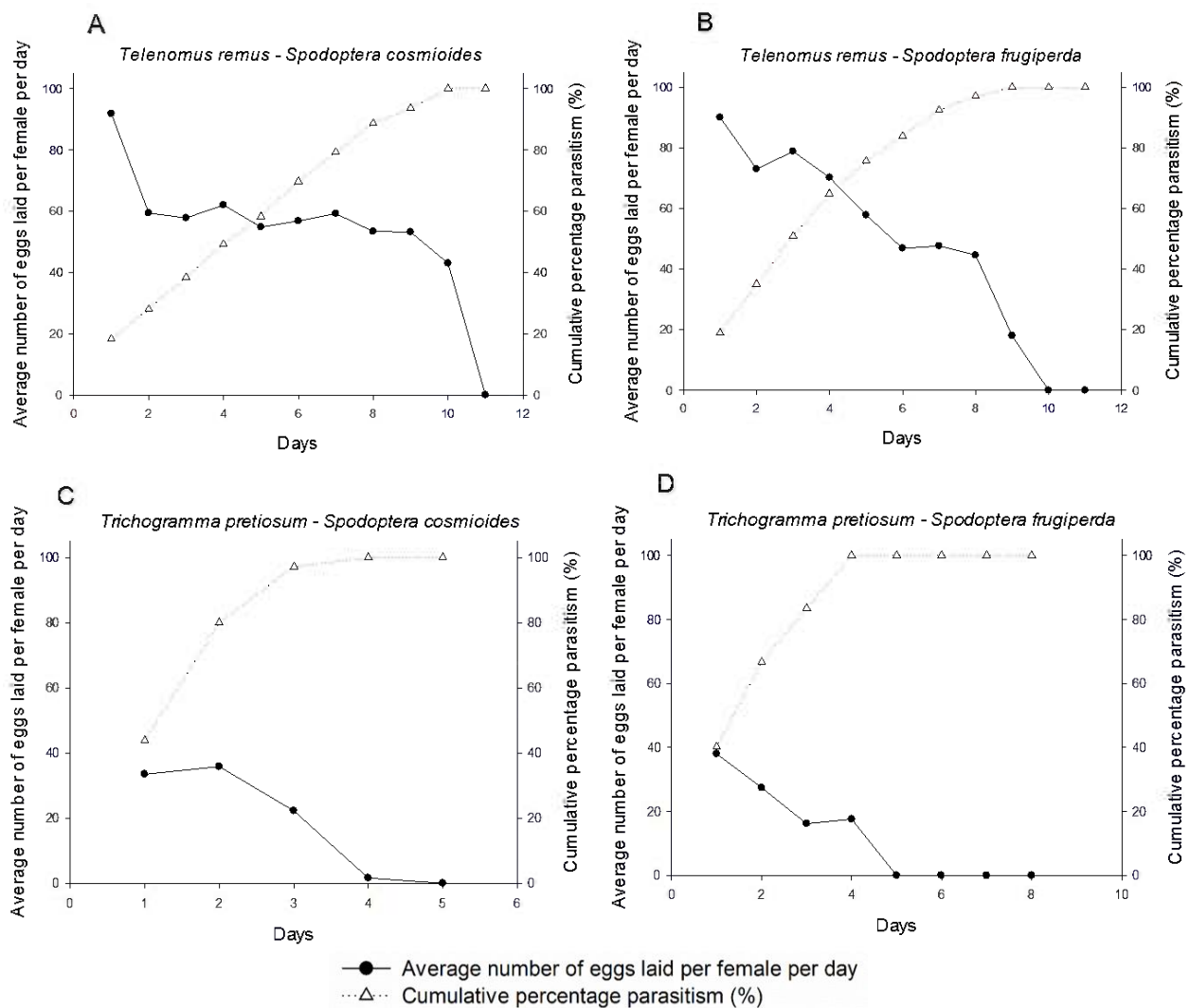


Figure 1. The average number of eggs laid per female per day and cumulative percentage parasitism of *T. remus* and *T. pretiosum* on *S. cosmioidea* (A, C) and *S. frugiperda* (B, D) eggs.

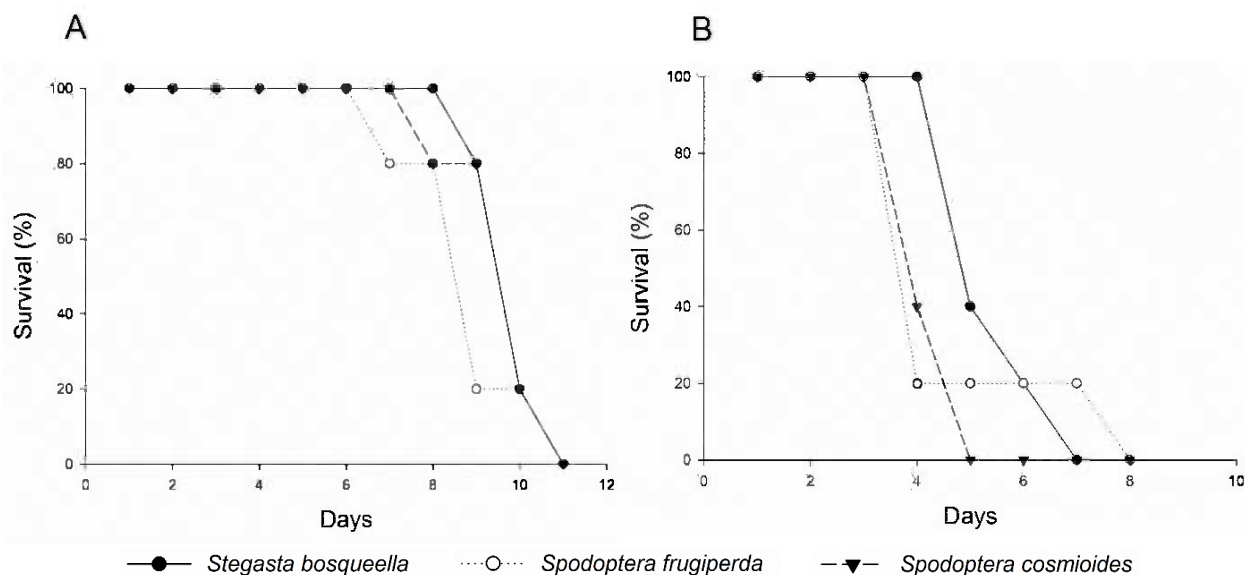


Figure 2. Survival curve of *T. remus* (A) and *T. pretiosum* (B) females maintained along with *S. bosqueella*, *S. cosmioidea* and *S. frugiperda* eggs as hosts.

The sex ratio (proportion females/total of parasitoids emerged) of the progenies differed ($F_{3,16} = 4.68$; $P = 0.0460$) between the parasitoid species. For *T. remus*, sex ratio was 0.61 ± 0.09 and 0.72 ± 0.10 from *S. cosmioidea* and *S. frugiperda*, respectively. Sex ratio of *T. pretiosum* was 0.38 ± 0.11 and 0.39 ± 0.06 from *S. cosmioidea* and *S. frugiperda*, respectively.

T. remus females survived, on average, 10.0 ± 0.3 , 9.8 ± 0.5 , and 9.0 ± 0.6 days, whereas females of *T. pretiosum* survived 5.6 ± 0.4 , 4.4 ± 0.2 , and 4.8 ± 1.8 days in the presence of *S. bosqueella*, *S. cosmioidea*, and *S. frugiperda* eggs, respectively. The longevity of the parasitoid females was not influenced by the host species ($F_{5,24} = 2.31$; $P = 0.1208$). However, *T. remus* showed significantly longer longevity than *T. pretiosum* ($F_{5,24} = 122.50$; $P < 0.0001$).

No significant difference was observed in the survival curves evidenced by the Log-Rank test for *T. remus* ($df = 2$, $\chi^2 = 0.4078$, $P = 0.8156$) and *T. pretiosum* ($df = 2$, $\chi^2 = 4.1125$, $P = 0.1279$) females (figure 2). Also, there was no mortality of *T. remus* and *T. pretiosum* females up to 6 and 3 days, respectively. However, after these periods, survival is 5-fold reduced at 9-10 days and no individual remained alive beyond 10 days. The mortality of *T. pretiosum* females occurred from the third day on, with no insects surviving more than 8 days.

Ultrastructure of the lepidopteran eggs

The eggs of *S. bosqueella* are 0.18 mm in diameter and 0.22 mm in height. They are ellipsoid and usually laid alone or in a small group (2-7 eggs). Groups of eggs were always found in a single layer egg mass. The chorion surface presents a rough texture and shows a reduced number of aeropyles (figure 3A-B). On the other hand, eggs of *S. cosmioidea* (figure 3C-D) and *S. frugiperda* (figure 3E-F) present 0.37 and 0.40 mm in diameter and 0.38 and 0.42 mm in height, respectively.

S. cosmioidea and *S. frugiperda* eggs are generally spherical in shape and grouped in 2-3 layers. These eggs present higher number of aeropyles compared to *S. bosqueella* eggs.

Discussion and conclusions

T. remus and *T. pretiosum* did not parasitize eggs of *S. bosqueella*, the main lepidopteran pest of peanut in Brazil, but did parasitize eggs of *S. cosmioidea* and *S. frugiperda* which are also important lepidopteran pests of peanut (Campos *et al.*, 2010; Boiça Junior *et al.*, 2013). The parasitism of *T. remus* was previously verified in eggs of different *Spodoptera* species (Pomari *et al.*, 2013a; Bueno *et al.*, 2014) in soybean, maize, and cotton (Pomari *et al.*, 2013b). *T. pretiosum* is able to parasitize *Tuta absoluta* (Meyrick) (Lepidoptera Gelechiidae) eggs (Pratisoli and Parra, 2000; 2001; Pratisoli *et al.*, 2004), but, *T. pretiosum* was unable to parasitize *S. bosqueella* eggs, although these lepidopteran species belong to the same family (Gelechiidae).

During the daily maintenance of insects in the glass tubes, we noticed that the parasitoids occasionally drummed *S. bosqueella* eggs, but they did not lay eggs. On the other hand, eggs of *S. cosmioidea* and *S. frugiperda* were promptly accepted as hosts. Female parasitoids can ascertain the suitability of the host visually or with the aid of the antennae, but the final acceptance usually depends on the evaluation of the quality of the host after insertion of the ovipositor (Godfray, 1994). The rejection of *S. bosqueella* eggs by the parasitoids may be related to a great variety of stimuli used by egg parasitoids to accept their hosts. In this context, the association between egg shape and size with semiochemicals on host acceptance by egg parasitoids has been previously described (Conti *et al.*, 1996; Vinson, 1998; Fatouros *et al.*, 2008).

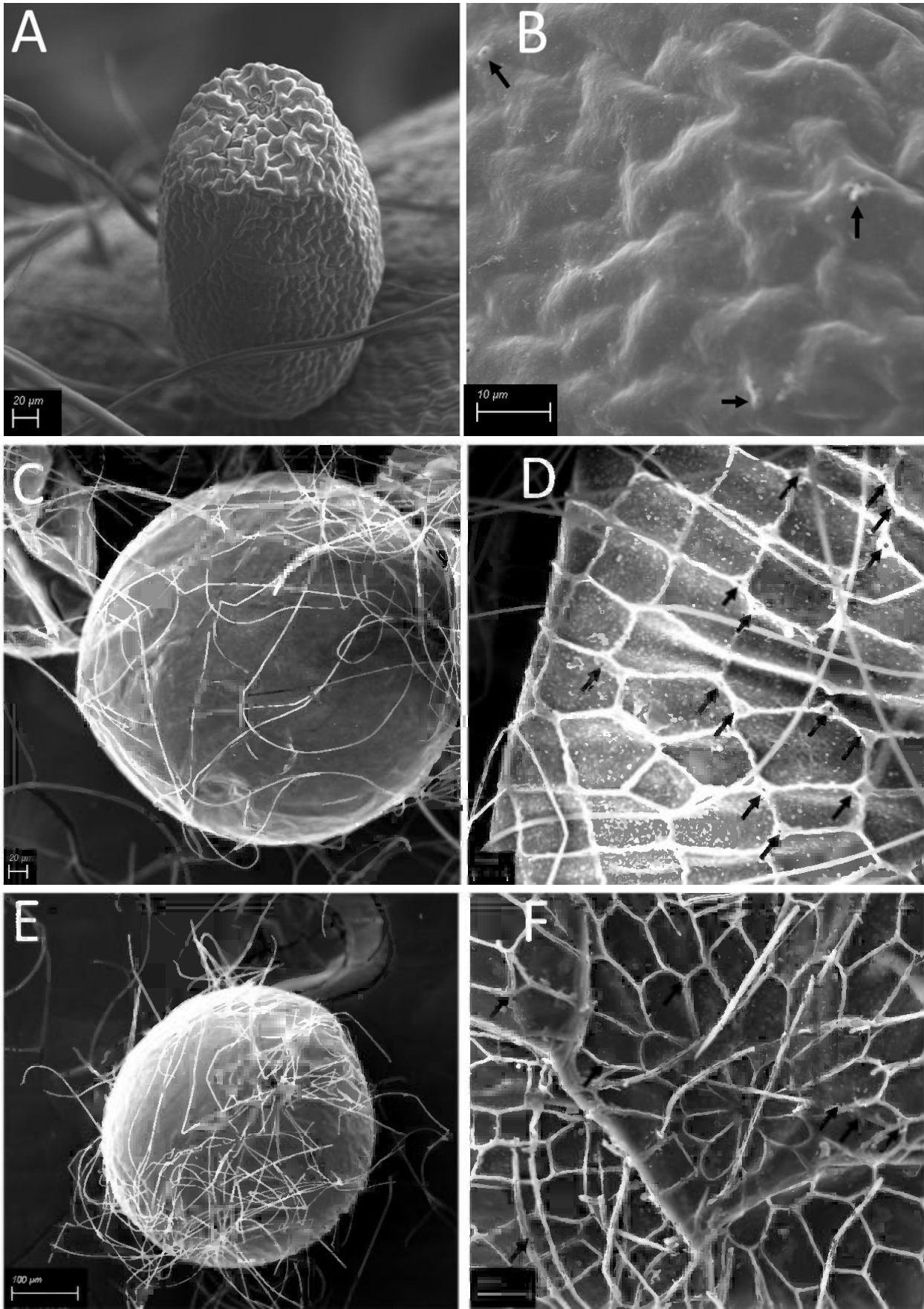


Figure 3. Images of the superficial structures of the egg and view of the openings of the micropyle and aeropyles (indicated by arrows) of *S. bosqueella* (A, B), *S. cosmioides* (C, D) and *S. frugiperda* (E, F).

According to Vinson (1998), the chemical cues emitted by the host species can be crucial to parasitoid oviposition. Moreover, in most of egg parasitoids, if the eggs are predictable as hosts, the parasitoids will drill the ovipositor to obtain information about the suitability (Godfray, 1994). So, the fact that the parasitoids did not drill *S. bosqueella* eggs can be related to the absence of chemical volatile cues that are necessary to stimulate oviposition. Kairomonal substances present on egg surface are very important in Trichogrammatidae and Scelionidae parasitoids to accept eggs as hosts (Colazza *et al.*, 2009).

Furthermore, for *T. remus*, the small size of *S. bosqueella* eggs (0.18 mm in diameter and 0.22 mm in height) may have been determinant for avoiding oviposition, because previous studies with *Telenomus heliothidis* Ashmead (Hymenoptera Scelionidae) indicated that only eggs between 0.50 and 0.63 mm in diameter are accepted as host (Strand and Vinson, 1983). For *Trichogramma* species, egg size is also important and can reduce progeny fitness (Bai *et al.*, 1992), considering that the host size seemingly define the host nutritional quality (Cônoli and Vinson, 2012).

In addition to chemical cues and egg size, the texture and thickness of the eggs of each host can be also decisive in the host selection, host acceptance and behaviour of egg parasitoids (Pak *et al.*, 1986; Vinson, 1998; Cônoli *et al.*, 1999). So, the surface (apparently rough) of *S. bosqueella* eggs, demonstrated on ultrastructure can be relevant. This behaviour was already reported by Pak *et al.* (1986) for *Trichogramma* spp. on *Mamestra brassicae* L. (Lepidoptera Noctuidae), *Pieris brassicae* L. (Lepidoptera Pieridae), and *Pieris rapae* L. (Lepidoptera Pieridae). The authors observed that drumming time was longer and penetration of the ovipositor and oviposition were more difficult on *M. brassicae* eggs due to probably the thicker chorion. Although, additional studies to evaluate the kairomones, structure, volume, and thickness of *S. bosqueella* eggs are required to obtain detailed information on this host species egg exploitation. This study brings new information on the evaluation of *T. remus* and *T. pretiosum* on eggs of *S. bosqueella* and two species of *Spodoptera* in peanut crop.

Although these parasitoids did not oviposit on *S. bosqueella* eggs, the longevity of females was not affected regardless the host. For parasitoids, it is known that host deprivation decreases egg load of females in several species, mainly through the egg resorption which leads to reduced fecundity, but increased longevity (Bruce *et al.*, 2009). Therefore, the fact that there was no significant difference between the females' longevity, even when parasitism was not observed, indicates that energy expenditure during oviposition on *Spodoptera* species did not affect their longevity.

The parasitism capacity observed in eggs of *S. cosmioides* and *S. frugiperda* was higher than the parasitism observed by Pomari *et al.* (2013a) and Bueno *et al.* (2014). However, these authors offered the hosts to the parasitoids using cardboard papers which may have affected the viability of eggs due to likely reduced moisture, because eggs on leaves are less negatively affected

by desiccation due the process of plant transpiration. Compared to *T. pretiosum* (3 days), *T. remus* required longer time (7 days) to achieve 80% of parasitism, although the latter parasitizes more hosts. Furthermore, this information suggests that both parasitoid species are able to parasitize *S. cosmioides* and *S. frugiperda* eggs rapidly and immediately after release, if they are used in biological control programs. Moreover, as these two moths can occur simultaneously, the use of *T. remus* or *T. pretiosum* shall increase their chances as biological control agents.

The highest parasitism activity of *T. remus* and *T. pretiosum* occurred within the first 24 hours. *T. remus* and *T. pretiosum* are pro-ovigenic species, because all their eggs are ready for oviposition upon emergence (Flanders, 1950; Wajnberg *et al.*, 2008; Cônoli *et al.*, 2010) and such an egg maturation strategy explains their larger concentration of parasitism activities during the first days of adulthood (Mills and Kuhlmann, 2000; Pomari *et al.*, 2013a). Parasitism concentrated in the first days is advantageous for applied biological programs, because it can guarantee a fast pest control and allows the application of other products in the short term, if necessary (Poorjavad *et al.*, 2011). This is an important aspect to be considered since commercial peanut cultivars grown in Brazil are susceptible to diseases and require bi-weekly applications of fungicides (Ruas, 2014). Therefore, future biological control programs using egg parasitoids in this crop should take into consideration avoidance of pesticide application during the first days after release or the use of selective products to reduce negative impact.

From the biological control standpoint, it is convenient to have a high proportion of females, as they are responsible for laying eggs on the host insect pest and, therefore, to biological control. Sex ratio of parasitoids can be influenced by the host size (Ueno, 2015), host species, and lineage of the parasitoid, showing that there is interaction between parasitoid and host (Carvalho *et al.*, 2017). *T. remus* presents naturally a female-biased sex ratio, which varies between 0.6 and 0.7 (Cave, 2000). The observed values for this species in our study varied between 0.61 and 0.72. *T. pretiosum* also presented similar sex ratio regardless of the *Spodoptera* species host (0.38 and 0.39). In view of this, it was found that even though these moths present similar egg sizes (figure 3), values of sexual ratio for *T. remus* are almost twice as much (84.62%) as values observed for *T. pretiosum*. This information indicates that for the main moth pests that occur in Brazilian peanut crop, *T. remus* progenies were female-based contrary to *T. pretiosum* whose sexual ratio was male-based.

In general, for *Spodoptera* species, *T. remus* presents greater control potential than *T. pretiosum* on peanut. *T. remus* can parasitize more eggs, presents greater longevity, and has a higher number of emerged females when compared to *T. pretiosum*. These characteristics were suggested as essential for selecting the best parasitoid candidate for biological control (Murdoch *et al.*, 2003; Kimberling, 2004).

On the other hand, these two parasitoids did not para-

sitize *S. bosqueella* eggs. Consequently, due to the importance of this insect in Brazilian peanut producing areas, other biological control agents or strains should be evaluated for this particular species.

The results of parasitism capacity obtained in this study are new and provide information on the performance of the egg parasitoids *T. remus* and *T. pretiosum* as potential biological control agents of *S. cosmioides* and *S. frugiperda*. This information may help in developing a biocontrol program of these important moth pests in peanuts.

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Authors' addresses: Odair Aparecido FERNANDES (corresponding author: odair.fernandes@unesp.br), José Ricardo Lima PINTO, Faculdade de Ciências Agrárias e Veterinárias, UNESP, Rod. Prof. Paulo Donato Castellane, km 5, 14884-900 Jaboticabal, SP, Brazil.

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