Neotropical Entomology
https://doi.org/10.1007/s13744-022-01020-2

BIOLOGICAL CONTROL IN LATIN AMERICA

Biology, Thermal Requirements, and Fertility Life Table of Strains of *Trichogramma foersteri* (Hymenoptera: Trichogrammatidae) in *Palpita forficifera* (Lepidoptera: Crambidae)

G. A. Villalba[1] · T. Scheunemann[1] · A. P. Krüger[1] · L. M. Corrêa[2] · D. Bernardi[1] · D. E. Nava[1,3]

Received: 7 March 2022 / Accepted: 21 December 2022

Abstract
Trichogramma foersteri Takahashi is a parasitoid recently identified in eggs of *Palpita forficifera* Munroe, considered the main pest of the olive tree in Brazil. The efficiency of a parasitoid is conditioned to several factors such as the temperature. The objective was to study the biology of the immature and adult phases at different constant temperatures (10, 15, 20, 25, and 30 °C), determine thermal requirements, and to elaborate a fertility life table for five strains (R1, R2, R3, R4, and R5) to *T. foersteri*. At 10 °C, there was no development of *T. foersteri.* The duration of the egg-adult period (days) was inversely related to temperature, ranging from 32 to 34 days (at 15 °C) to 6.5 to 7.5 days (at 30 °C). The thermal range evaluated did not influence parasitism (parasitism > 57%) and the sex ratio (sr > 0.74). The base temperature (Tt) was similar for all strains (approximately 12 °C), corresponding to a thermal constant (K) of 120.48 to 145.13 degree days. For the adult stage, *T. foersteri* had the highest rate of parasitism (> 48%) to 15 °C. The emergence rate ranged from 75 to 100%. The thermal range did not influence the sex ratio of the lines (sr > 0.70), but reduced the longevity from 50 days (at 15 °C) to 6 days (at 30 °C). Regarding the fertility life table, all strains of *T. foersteri* showed biological potential of development and growth in eggs of *P. forficifera* in the thermal range of 15 to 30 °C, important information for the establishment of biological control programs.

Keywords Egg parasitoid · Olive pest · Thermal requirements · Parasitism capacity

Introduction

One of the main limiting factors for the production of olive trees in the Rio Grande do Sul State is the olive worm *Palpita forficifera* Munroe, 1959 (Lepidoptera: Crambidae), considered the most frequent pest in crops and the most important in economic terms (Ricalde and Garcia 2013). The damage is caused by the larvae, which feed on the shoots. However, in high infestations, they can attack senescent leaves, flowers, and fruits (Scheunemann et al. 2019). The main consequence of the pest attack on cultivation is a reduction in the following year's production since the olive tree produces olives on the previous year's growth.

The management of the olive worm has been difficult due to the lack of options for its control since the olive tree plantations are recent and also to the fact that crop pests are unique to the olive tree in relation to traditional cultivation regions and have few hosts (Ricalde and Garcia 2013). In addition, the control of insect pests in olive groves in Brazil is carried out with only one commercial product, which has been an obstacle to the adoption of integrated pest management (Agrofit 2022). In this way, the search for alternatives for the management of *P. forficifera* has been directed towards biological control and thus, to enable its use, studies with potential biocontrol agents are needed (Scheunemann et al. 2019).

Edited by Yelitza C Colmenarez

✉ D. E. Nava
dori.edson-nava@embrapa.br

[1] Programa de Pós-Graduação em Fitossanidade, Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, Pelotas, Rio Grande do Sul, Brazil

[2] Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, Pelotas, Rio Grande do Sul, Brazil

[3] Embrapa Clima Temperado, Pelotas, Rio Grande do Sul, Brazil

Published online: 19 January 2023

The use of parasitoids, especially species of the genus *Trichogramma* (Hymenoptera: Trichogrammatidae), in the initial phase of insect pest development (egg stage), has been a recommended practice in integrated pest management (IPM) to reduce the use of chemical pesticides in agriculture (Parra and Coelho Jr. 2019). In Brazil, there are several successful cases of the use of *Trichogramma* spp. reported for the control of different lepidopteran pest species in crops of agricultural importance, especially sugarcane, soybean, tomato, grape, and avocado (Coelho Jr. et al. 2019). In the olive tree, several strains of *Trichogramma* spp. may be employed identified as being *Trichogramma foersteri* Takahashi, 2021 (Hymenoptera: Trichogrammatidae) (Ranyse Barbosa Querino, personal communication). However, in addition to identification, one of the first steps for the implementation of a biological control program is to carry out studies to verify the potential biotype of the parasitoid on the host (Davies et al. 2011; Parra and Coelho Jr 2022) as well as verifying the favorable environmental conditions to exploit this potential to the fullest (Bueno et al. 2012; Carvalho et al. 2017) since temperature is considered a crucial factor for the multiplication, establishment, and adaptation of the natural enemy in specific place (Silveira Neto et al. 1976; Firake et al. 2014; Figueiredo et al. 2015). *Trichogramma foersteri* is a species that was recently described in eggs of *Anticarsia gemmatalis* Hübner, 1818 (Lepidoptera: Erebidae) (Takahashi et al. 2021) and has demonstrated high rates of parasitism in *P. forficifera* (Nava D.E., Informação pessoal). In addition, the choice of a species adapted to the climate conditions and present in the olive cultivation system is fundamental factors if the biological control program is to be successful (Parra 2021). In view of the lack of information on the biological aspects of *T. foersteri* in eggs of *P. forficifera*, considered a key pest of olive growing in Rio Grande do Sul State, Brazil, the objective was to study the biology of parasitoid strains R1, R2, R3, R4, and R5, under different thermal conditions and from this information to determine the thermal requirements and the fertility life table.

Material and methods

The study was performed in the laboratory in an air-conditioned rooms with different constant temperatures of 10, 15, 20, 25, and 30 ± 1 °C, relative humidity of 70 ± 10%, and 14 h photophase.

Rearing and maintenance of *P. forficifera*

The rearing of the host was carried out on a natural diet using olive shoots that were offered daily to the larvae according to Scheunemann et al. (2019). The larvae were kept in a container made of plastic (20 × 40 cm and 15-cm deep), which also served as a pupation site. At the beginning of the emergence, the adults were transferred to containers made of transparent PET bottles (5L) (22 cm high × 16 cm in diameter). The upper part was closed with a fine tissue (tulle) fixed with an elastic band. In the containers, food was offered based on a 10% honey solution (water and honey) and pure water, offered via capillarity in hydrophilic cotton arranged in 10-ml Falcon-type plastic tubes, adapted with a longitudinal opening. Eggs were obtained from the oviposition substrate (filter paper) placed on the tulle at the top of the container. A sponge cloth was placed over the paper (Spontex™, Panesponja, Ilhéus, Brazil) in order to maintain moisture and prevent dehydration of the eggs. During the oviposition period, the filter paper containing the eggs was removed daily. Part of the egg laying was destined for the maintenance of the rearing of *P. forficifera* according to Scheunemann et al. (2019) and another part was destined for the biology experiments of the strains of *T. foersteri*.

Obtaining the parasitoids and rearing maintenance

The five strains of *T. foersteri* used in the work represent the five collections where it was possible to establish laboratory rearing. *Trichogramma foersteri* was collected in two olive orchards in the municipality of Pelotas (31°40′55″S, 52°26′11″W, and 31°37′05″S, 52°31′00″W, with about 0.2 and 1 ha, respectively) and in one olive orchard in Rio Grande (31°57′04″S, 52°18′35″W with about 0.5 ha), Rio Grande do Sul State. For this, cardboard cards (2 × 2 cm) containing eggs of *P. forficifera* were fixed in the branches of the olive trees. The cards remained exposed to parasitism for 24 h and were then collected and kept in the laboratory to observe the parasitism of the eggs of *P. forficifera*. The eggs were separated and individualized according to the place and date of collection and defined as strains R1, R2, R3, R4, and R5. Parasitism was indicated by the darkening of the chorion of the eggs. Each strain was reared separately in glass tubes (20 cm long × 10-cm diameter) with rearing and maintenance procedures performed separately to avoid contamination. After emergence, the adults were fed with honey arranged in lines on the glass side of each tube. In addition, moistened filter paper of approximately 2 cm in diameter was placed in order to avoid drying out the host (*P. forficifera* egg) and thus compromising the survival of the parasitoid. Subsequently, the lines were maintained through the daily offering of eggs of *P. forficifera* up to 12 h of age, offered in cardboard cartons (± 2000 eggs per carton), for a period of 24 h. Subsequently, the cards were removed and placed in glass tubes (20 cm in length × 10 cm in diameter) sealed with PVC plastic film and kept in an acclimatized room with a temperature of 25 ± 1 °C, relative air humidity of 70 ± 10%, and photophase of 14 h until the emergence of parasitoids to start the bioassays.

Trichogramma foersteri was identified through an integrative taxonomic analysis taking into account the morphological and molecular analysis. Identification was performed by Dr. Ranyse Barbosa Querino da Silva, from Embrapa Cerrados.

Biological parameters of the immature stage of *T. foersteri* at different temperatures

About 1500 eggs of *P. forficifera* were offered for a period of 12 h to females of *T. foersteri* of 1 day of the five strains (R1, R2, R3, R4, and R5), being kept at 25 ± 1 °C, relative humidity of 70 ± 10%, and photophase of 14 h. After parasitism, eggs were transferred onto cards with 30 eggs and placed in glass tubes (8.5 cm high × 2.5 cm in diameter) closed with Magipack® plastic film and distributed in acclimatized chambers at temperatures of 10, 15, 20, 25, and 30 ± 1 °C. The development of parasitoids was monitored daily until emergence. The variables analyzed were duration of the egg-adult period (days), number of parasitized eggs, and sex ratio [sr = female/(female + male)]. The experiment was carried out in a completely randomized design with five treatments (temperatures) and six replications (cards containing 30 eggs of *P. forficifera*).

Biological parameters of the adult stage of *T. foersteri* at different temperatures

Twenty-five pairs of *T. foersteri* with up to 12 h of age of the strains R1, R2, R3, R4, and R5 of *T. foersteri* from different temperatures were individualized in glass tubes (8.5 × 2.5 cm), closed with PVC plastic film. For the feeding of the adults, a thread of honey was provided every 48 h, placed on the inner wall of the tube. Subsequently, the insects were kept in acclimatized chambers with constant temperatures (treatments) of 10, 15, 20, 25, and 30 ± 1 °C, relative air humidity of 70 ± 10%, and photophase of 14 h. Daily until the 15th day or the death of the females, filter paper cards were offered (1.5 × 2 cm) (laying substrate) containing 30 eggs of *P. forficifera* up to 12 h old. After 24 h of parasitism, the cards were removed and transferred to other glass tubes (8.5 × 2.5 cm), closed with plastic PVC film, and kept in acclimatized chambers regulated at a temperature of 25 ± 1 °C, relative humidity of 70 ± 10%, and a photophase of 14 h, until the emergence of the parasitoids. The experimental design used was completely randomized with five treatments (temperatures) and 25 replications (pairs) of each strain. The biological parameters evaluated were duration of the egg-adult period (days), percentage (%) of parasitism and emergence, and sex ratio [sr = female/(female + male)] and longevity (days) of parasitoids. Based on the results obtained from the biological parameters evaluated in the immature and adult stages, the fertility life table was created estimating the average generation time (T), the net reproduction rate (R_o), the intrinsic rate of growth (R_m), and the finite rate of increase (λ) (Southwood 1995).

Statistical analysis

The duration (days) of the biological cycle (egg to adult) and parasitism (%) were subjected to the Shapiro–Wilk normality test and Hartley's and Bartlett's homoscedasticity test. Subsequently, the means were subjected to analysis of variance (ANOVA) through the F test ($P \leq 0.05$) using the SAS® GLM procedure (SAS Institute 2011). When statistically significant, the means were compared by Tukey's test ($P \leq 0.05$). The possible deviation in the sex ratio was compared by the chi-square test (χ^2) ($P \leq 0.05$) (PROC FREQ, SAS Institute 2011). Longevity (days) of *Trichogramma* adults was assessed by survival curves using the Kaplan–Meier estimator and subsequently compared by log-rank test with the aid of R® software (R Development Core Team 2011). The thermal requirements of the immature stages (eggs to adults) of *Trichogramma* were estimated using the hyperbola method (Haddad et al. 1999), calculating the lower limit for temperature or the temperature threshold (Tt) and the thermal constant (K) (SAS Institute 2011). The fertility life table parameters were estimated by the Jackknife method using Lifetable. SAS software (Maia et al. 2000), and the means were compared by the bilateral t test ($P \leq 0.05$) with SAS® software (SAS Institute 2011). Differences between treatments were evaluated at a significance level of α = 0.05 SAS ® (SAS Institute 2011).

Results

There was no embryonic development of *T. foersteri* at a temperature of 10 °C for any of the evaluated strains (Table 1). By jointly analyzing the egg to adult developmental periods (days) for all strains of *T. foersteri*, there was a significant decrease ($P \leq 0.05$) in duration with increasing temperature (Table 1). The shortest development periods (ranging from 6.5 to 7.5 days) were observed at 30 °C (Table 1). However, the different temperatures did not significantly influence the rate of parasitism and the sex ratio of insects within and between strains of *T. foersteri* (Table 1). However, the number of females was always greater than the number of males, characterizing a variable sex ratio from 0.74 to 1.0 at all temperatures evaluated (Table 1).

Based on confidence intervals, there were no significant differences between base temperature values (Tt), with values ranging from 12.09 °C (strain R5) to 12.98 °C (strain R2) (Table 2), corresponding to a thermal constant (K) of 145.13 to 120.48 degree days, respectively (Table 2). Through the linear equation of developmental speed, all the

Table 1 Mean (±standard error) duration (days) of the egg to adult period, percentage of parasitism, and sex ratio of five strains of *Trichogramma foersteri* raised at different temperatures in eggs of *Palpita forficifera*

Treatments	Temperature (°C)					
	10*	15	20	25	30	
Duration (egg to adult)						
R1	-	33.0 ± 0.76A^{ns}	24.0 ± 0.76 aB	12.5 ± 0.00 aC	7.5 ± 0.00 aD	F = 10.13; df = 4. 25; P < 0.0001
R2	-	34.0 ± 0.76A	22.0 ± 0.76 bB	10.5 ± 0.00 bC	6.5 ± 0.00bD	F = 17.90; df = 4. 25; P < 0.0001
R3	-	33.0 ± 0.76A	24.0 ± 0.70 aB	11.5 ± 0.00 abC	7.5 ± 0.00 aD	F = 8.34; df = 4. 25; P < 0.0001
R4	-	32.0 ± 0.76A	24.0 ± 0.80 aB	12.5 ± 0.00 aC	7.5 ± 0.00 aD	F = 8.00; df = 4. 25; P < 0.0001
R5	-	32.0 ± 0.75A	24.0 ± 0.70 aB	12.0 ± 0.00 aC	7.5 ± 0.00 aD	F = 8.12; df = 4. 25; P < 0.0001
F		4.11	3.17	2.13	5.10	
df		4. 25	4. 25	4. 25	4. 25	
P		= 0.2231	< 0.0001	< 0.0001	< 0.0001	
Parasitism (%)						
R1	-	60.8 ± 3.83A^{ns}	59.8 ± 6.49A^{ns}	58.5 ± 3.54A^{ns}	59.5 ± 2.96A^{ns}	F = 22.14; df = 4. 25; P = 0.1134
R2	-	57.6 ± 8.57A	61.5 ± 2.29A	62.6 ± 5.08A	57.6 ± 4.55A	F = 15.44; df = 4. 25; P = 0.3218
R3	-	60.3 ± 3.10A	62.6 ± 3.91A	61.6 ± 2.32A	56.1 ± 4.82B	F = 12.44; df = 4. 25; P = 0.1211
R4	-	60.0 ± 2.73A	62.3 ± 2.66A	61.0 ± 2.50A	60.6 ± 1.28A	F = 13.56; df = 4. 25; P = 0.1211
R5	-	62.2 ± 2.67A	59.0 ± 5.09 A	59.2 ± 2.54A	56.3 ± 5.02A	F = 18.10; df = 4. 25; P = 0.1211
F		11.12	10.09	12.24	10.31	
df		4. 25	4. 25	4. 25	4. 25	
P		= 0.0734	= 0.0984	= 0.0231	= 0.0146	
Sex ratio						
R1	-	0.79 ± 0.04A**	0.74 ± 0.05A**	0.77 ± 0.03A**	0.81 ± 0.07A**	χ^2 = 35.11; df = 4. 25; P = 0.2213
R2	-	0.81 ± 0.08A	0.85 ± 0.05A	0.77 ± 0.04A	0.77 ± 0.02A	χ^2 = 44.87; df = 4. 25; P = 0.1132
R3	-	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	χ^2 = 42.90; df = 4. 25; P = 0.1021
R4	-	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	χ^2 = 44.17; df = 4; 25; P = 0.3544
R5	-	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	1.00 ± 0.00A	χ^2 = 41.90; df = 4. 25; P = 0.1125
χ^2		4.11	2.10	5.17	6.11	
df		4. 25	4. 25	4. 25	4. 25	
P		= 0.2202	= 0.2677	= 0.1144	= 0.1021	

*Temperature not used for statistical analysis, as there was no development. Means followed by the same lowercase letter in columns and uppercase in rows do not differ statistically from each other, Tukey test, $p < 0.05$. ns, not significant in the column by the Tukey test, $p < 0.05$; **not significant by the chi-square test

Table 2 Lower thermal threshold of development (Tt), thermal constant (K), development speed linear Eq. (1/D), and coefficient of determination (R^2) from the egg-adult phase of strains of *Trichogramma foersteri* in eggs of *Palpita forficifera*

Strains	Tt (°C)	K (DD)	Linear regression equation	R^2	F	P-value
R1	12.23 (12.01–12.32)	144.50	y = −0.08502 + 0.00692x	0.93	26.97	0.1113
R2	12.98 (12.30–13.04)	120.48	y = −0.10775 + 0.00830x	0.93	26.92	0.1018
R3	12.14 (12.10–12.32)	137.90	y = −0.08806 + 0.00725x	0.95	38.12	0.0252
R4	12.11 (12.01–12.26)	145.13	y = −0.08350 + 0.00689x	0.93	25.33	0.1193
R5	12.09 (12.03–12.35)	143.67	y = −0.08417 + 0.00696x	0.95	28.96	0.0328

lineages of *T. foersteri* demonstrated that 93% of the time the decrease in development time was explained by the increase in temperature ($R^2 > 0.93$) (Table 2).

In the adult stage, *T. foersteri* had the highest rate of parasitism (> 48%) when exposed to 15 °C (Table 3). However, significant variations between the strains of *T. foersteri* were observed in the percentage of emergence (Table 3). Based on the chi-square test, the sex ratio was significantly similar for all strains and temperatures evaluated (range 0.6 to 1.0) (Table 3). However, adults kept at 15 °C were the longest-lived, with ages ranging from 51.7 days (R2 strain) to 58.0 days (R4 strain) (Table 3). In contrast, when kept at 30 °C, longevity was approximately 6 days (Table 3).

Table 3 Mean (± standard error) of the percentage of parasitism, emergence, sex ratio, and longevity of five strains of *Trichogramma foersteri* when adults were reared at different temperatures in eggs of *Palpita forficifera*

Strains	Temperature (°C)					
	10*	15	20	25	30	
Parasitism (%)						
R1	-	49.5 ± 3.50Aa	40.2 ± 4.5Bab	31.0 ± 4.9Bb	40.0 ± 4.0Bab	$F = 14.10$; df = 3. 96; $P < 0.0001$
R2	-	49.5 ± 3.8Aa	41.2 ± 3.5Ba	40.8 ± 5.4Ba	38.2 ± 3.9Bbc	$F = 10.08$; df = 3. 96; $P < 0.0001$
R3	-	48.7 ± 4.5Aa	40.5 ± 4.0ABab	43.7 ± 3.2ABa	31.0 ± 3.2Cc	$F = 12.34$; df = 3. 96; $P < 0.0001$
R4	-	48.8 ± 1.10Aa	36.3 ± 2.5Bbc	36.7 ± 2.2Bab	35.0 ± 2.9Bbc	$F = 18.11$; df = 3. 96; $P < 0.0001$
R5	-	50.0 ± 2.3Aa	31.8 ± 3.7Cc	37.2 ± 5.0BCab	43.5 ± 2.8Ba	$F = 13.10$; df = 3. 96; $P < 0.0001$
F		2.13	7.11	2.09	6.43	
df		4. 119	4. 119	4. 119	4. 119	
P		= 0.2231	< 0.0001	< 0.0001	< 0.0001	
Emergence (%)						
R1	-	95.3 ± 4.1Aa	94.4 ± 4.1Aa	75.0 ± 8.80Bc	99.0 ± 0.9Aa	$F = 23.12$; df = 3. 96; $P = 0.0967$
R2	-	90.9 ± 5.0Aa	99.1 ± 0.5Aa	100.0 ± 0.00Aa	91.1 ± 5.6Aa	$F = 25.10$; df = 3. 96; $P = 0.1110$
R3	-	88.8 ± 5.6Aa	93.8 ± 4.1Aa	79.2 ± 8.3Ac	98.0 ± 1.6Aa	$F = 22.12$; df = 3. 96; $P = 0.1911$
R4	-	98.3 ± 0.9Aa	94.1 ± 4.1ABa	83.3 ± 7.6Bbc	91.0 ± 5.6ABa	$F = 23.06$; df = 3. 96; $P < 0.0001$
R5	-	98.6 ± 0.7Aa	94.0 ± 4.1Aa	91.7 ± 5.6Aab	99.9 ± 0.1Aa	$F = 28.01$; df = 3. 96; $P = 0.1312$
F		22.09	15.64	10.11	21.08	
df		4. 119	4. 119	4. 119	4. 119	
P		= 0.0231	= 0.0977	< 0.0001	= 0.0201	
Sex ratio						
R1	-	0.8 ± 0.1**^{ns}	0.8 ± 0.1**	0.6 ± 0.1**	0.8 ± 0.1**	$\chi^2 = 21.10$; df = 3. 96; $P = 0.1231$
R2	-	0.8 ± 0.1 ^{ns}	0.8 ± 0.1	0.6 ± 0.2	0.9 ± 0.0	$\chi^2 = 36.07$; df = 3. 96; $P = 0.1098$
R3	-	0.9 ± 0.1 ^{ns}	1.0 ± 0.0	0.8 ± 0.1	1.0 ± 0.0	$\chi^2 = 32.12$; df = 3. 96; $P = 0.1212$
R4	-	1.0 ± 0.0 ^{ns}	1.0 ± 0.0	0.8 ± 0.1	1.0 ± 0.0	$\chi^2 = 28.17$; df = 3. 96; $P = 0.0243$
R5	-	1.0 ± 0.0 ^{ns}	1.0 ± 0.0	0.9 ± 0.1	1.0 ± 0.0	$\chi^2 = 31.10$; df = 3. 96; $P = 0.1100$
χ^2		2.10	5.12	3.18	6.09	
df		4. 119	4. 119	4. 119	4. 119	
P		= 0.0896	= 0.1134	= 0.1354	= 0.0944	
Longevity (days)						
R1	-	57.9 ± 1.6Aa	26.3 ± 1.3Ba	10.3 ± 0.7Cb	6.0 ± 0.3 Da	$F = 4.10$; df = 3. 96; $P < 0.0001$
R2	-	51.7 ± 3.9Aa	24.2 ± 1.0Ba	10.2 ± 0.4Cb	5.9 ± 0.3 Da	$F = 2.08$; df = 3. 96; $P < 0.0001$
R3	-	57.0 ± 2.2Aa	25.4 ± 1.3Ba	10.8 ± 0.5Cab	5.9 ± 0.3 Da	$F = 2.34$; df = 3. 96; $P < 0.0001$
R4	-	58.0 ± 2.7Aa	23.9 ± 1.4Ba	12.1 ± 0.4Ca	5.9 ± 0.3 Da	$F = 5.78$; df = 3. 96; $P < 0.0001$
R5	-	55.5 ± 2.5Aa	24.0 ± 1.1Ba	11.2 ± 0.7Cab	6.2 ± 0.3 Da	$F = 3.22$; df = 3. 96; $P < 0.0001$
F		7.12	8.18	4.15	3.19	
df		4. 119	4. 119	4. 119	4. 119	
P		= 0.1021	= 0.1398	< 0.0001	= 0.1765	

*Temperature not used for statistical analysis, as there was no development. Means followed by the same lowercase letter in columns and uppercase in rows do not differ statistically from each other, Tukey test, $p < 0.05$. *ns*, non-significant in line by the chi-square test; **not significant in the column by the chi-square test

Regarding the fertility life table, temperatures of 15, 20, 25, and 30 °C provided the species with a biological potential for development (Table 4). However, significant variations were observed between the strains evaluated within each temperature for the duration of each generation (T), the net reproduction rate (R_o), the intrinsic rate of growth (R_m), and the finite rate of increase (λ) (Table 4). The shortest periods of T (days) between generations were observed at 30 °C (ranging from 16 to 19 days) (Table 4). However, at 15 °C, this variation was from 49 to 53 days. Regarding the net reproductive rate (Ro), the R3 strain differed statistically from the other strains studied within each temperature (Ro > 20) (Table 4). In general, these significant differences were maintained when analyzing the intrinsic rate of growth (rm) and finite rate of increase (λ).

Table 4 Fertility life table of strains of *Trichogramma foersteri* at different temperatures in eggs of *Palpita forficifera*

Temperatures/**strains**	T (days)	R_o (♀/♀)	r_m (♀/♀ [days])	λ
15 °C				
R1	51.6 ± 1.60 ab	11.5 ± 0.10 b	0.008 ± 0.001 c	1.008 ± 0.001 c
R2	52.3 ± 1.34 a	11.6 ± 0.09 b	0.009 ± 0.001 c	1.009 ± 0.001 c
R3	49.3 ± 1.70 b	20.8 ± 0.99 a	0.048 ± 0.003 a	1.050 ± 0.003 a
R4	53.9 ± 1.54 a	11.1 ± 0.23 b	0.003 ± 0.001 c	1.003 ± 0.003 c
R5	53.0 ± 1.7 a	12.7 ± 0.23 b	0.019 ± 0.002 b	1.019 ± 0.003 b
20 °C				
R1	36.5 ± 1.46 a	11.1 ± 0.12 c	0.003 ± 0.001 b	1.000 ± 0.001 a
R2	35.8 ± 1.60 a	11.3 ± 0.11 c	0.009 ± 0.001 b	1.009 ± 0.001 a
R3	35.1 ± 1.70 a	24.5 ± 0.21 a	0.023 ± 0.001 a	1.011 ± 0.002 a
R4	35.4 ± 1.74 a	22.1 ± 0.21 b	0.021 ± 0.002 a	1.001 ± 0.003 a
R5	35.4 ± 1.65 a	10.5 ± 0.07 c	0.002 ± 0.001 b	1.012 ± 0.001 a
25 °C				
R1	23.7 ± 2.10 a	11.0 ± 0.03 c	0.002 ± 0.001 d	1.000 ± 0.001 b
R2	20.9 ± 1.98 a	11.6 ± 0.22 c	0.020 ± 0.006 c	1.024 ± 0.006 b
R3	21.2 ± 2.24 a	22.5 ± 0.34 a	0.097 ± 0.008 a	1.140 ± 0.008 a
R4	23.6 ± 1.95 a	11.8 ± 0.26 c	0.026 ± 0.006 c	1.026 ± 0.006 b
R5	20.6 ± 1.53 a	17.4 ± 1.01 b	0.073 ± 0.002 b	1.102 ± 0.011 a
30 °C				
R1	17.4 ± 1.79 a	11.7 ± 0.14 b	0.030 ± 0.005 c	1.031 ± 0.005 b
R2	16.2 ± 1.77 a	11.2 ± 0.12 b	0.012 ± 0.002 c	1.012 ± 0.006 b
R3	18.9 ± 1.77 a	20.9 ± 0.02 a	0.160 ± 0.001 a	0.193 ± 0.005 a
R4	16.4 ± 1.60 a	18.1 ± 0.86 b	0.131 ± 0.003 b	1.170 ± 0.004 a
R5	19.6 ± 1.70 a	11.8 ± 0.15 b	0.031 ± 0.001 c	1.031 ± 0.005 ab

[1]Values represent the average ± standard error obtained by the Jackknife method in SAS software

T, generation time; R_o, net reproductive rate; r_m, intrinsic rate of increase; λ, finite rate of increase

Different letters within the same temperature indicate significant differences within a line [(Tukey's test), $P < 0.05$]

Discussion

An important aspect to determine insect population dynamics is based on biology and the estimation of the optimal temperature for the development of the biological cycle in the natural environment (Buckley et al. 2017). For five strains of the *T. foersteri* in *P. forficifera* eggs, the temperature of 10 °C is considered inadequate for the development of this natural predator. However, when evaluating the biological performance at temperatures above 15 °C, small intraspecific biological differences were observed, and all temperatures provided the development of the parasitoid. According to other studies with species of *Trichogramma*, the significant variations that may occur within the population may be associated with a natural phenomenon related to the variability of the species or adaptation to the host (Pereira et al. 2004; Zago et al. 2007; Oliveira et al. 2017; Pratissoli et al. 2021). This fact is evidenced when evaluating the strains (R1, R2, R3, R4, and R5) belonging to the same species, with only the place of collection as a variable factor.

The maintenance of the parasitism rate in a wide range of thermal variation, as observed for *T. foersteri*, is a positive indicator as it allows releases at different times of the year since *P. forficifera* attacks the olive groves from the months of spring to autumn in the south of Brazil. In addition, the prevalence of parasitoid development within a wide temperature range is important for the maintenance, breeding, and multiplication of insects in the laboratory, especially at temperatures that are similar to the conditions of the study region (Ramos Coutinho et al. 2021), as observed in the present work. Based on the base temperature (Tt) and the thermal constants (K), it can be estimated for the municipalities of Rio Grande and Pelotas, microregions producing olive trees in the state of Rio Grande do Sul, that *T. foersteri* can complete 30.41 generations in these regions. This information may help in the elaboration of management models for the olive worm, as well as in the production of this parasitoid under laboratory conditions.

One of the factors that contribute to the increase in parasitism and the success of biological control is the presence of a greater number of females in the insect population

(Parra and Coelho Jr. 2019; Ramos Coutinho et al. 2021). In the present study, the sex ratio was similar between *T. foersteri* strains. It is worth noting that three (strains R3, R4, and R5) of the five studied strains presented only females as descendants or, in general, the number of males in the strains is very small, indicating the occurrence of thelytokous parthenogenesis (Ramos Coutinho et al. 2021). The presence of a greater number of females in the population may increase the growth rate of the species under field conditions since males do not contribute to the mortality of the host (Nava et al. 2007). However, a large number of females can also favor superparasitism, causing death to the host and having a negative effect on the density of the natural predator (Nava et al. 2007). In addition, the presence of males in the population is considered essential to maintain the genetic variability of the population and thus increase the biological potential of the species (Parra and Coelho Jr. 2019; Oliveira et al. 2019; Ramos Coutinho et al. 2021).

Through the parameters of the fertility life table, the development and multiplication capacity of the *T. foersteri* in eggs of *P. forficifera* were accessed over generations. Fertility life table studies have been used to assess the growth potential of parasitoid species subjected to different temperatures (Oliveira et al. 2017; Pratissoli et al. 2021). For the present study, significant variations were obtained between strains and within each temperature. However, all strains evaluated showed positive values of population growth, demonstrating the ability of the species to grow over time and avoid the extinction of the species in eggs of *P. forficifera*.

Biological control using egg parasitoids of the genus *Trichogramma* has been widely explored as an alternative to the application of synthetic chemical insecticides in pest management, mainly for insect species of the Lepidoptera order (Parra 2014; Parra and Coelho Jr. 2021). For olive tree culture, the discovery of a native species in the agricultural orchards of the southern region of Brazil, associated with the biological development capacity of the species and eggs of *P. forficifera* at different temperatures, demonstrates the future potential for the use of this control agent in pest management. However, semi-field and field tests must be performed to adjust and optimize the release methodology and the association of this parasitoid with other pest control techniques.

Acknowledgements The authors would like to thank the Coordination for Perfecting Higher Education Personnel (CAPES) for the concession of scholarships for the first five authors (Financing Code 001) and the National Council of Technological and Scientific Development (CNPq) for the productivity scholarship provided to the seventh author. We thank to Dr. Ranyse Barbosa Querino da Silva, from Embrapa Cerrados, and to Leonardo Castelo Branco Carvalho, from Univerdade Federal Rural da Amazonia for the identification of *Trichogramma foersteri*.

Author contribution G. A. V.: investigation, methodology, data curation and writing—original draft; T. S.: investigation, methodology, and data curation; A. P. K.: data analysis and conducting statistical analyses; L. M. S. C.: investigation, methodology, and data curation; D. B.: writing—original draft and data analysis and conducting statistical analyses; D. E. N.: conceptualization, funding acquisition, project administration, supervision, writing—original draft, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Data availability The data set is available from the corresponding author and may be passed on to interested parties upon request to Embrapa Clima Temperado.

Declarations

Conflict of interest The authors declare no competing interests.

References

AGROFIT. Sistema de agrotóxicos fitossanitários. (2017). Disponível em: https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Acesso em: 07 fev. 2022.

Buckley LB, Arakaki AJ, Cannistra AF, Kharouba HM, Kingsolver JG (2017) Insect development, thermal plasticity and fitness implications in changing, seasonal environments. Integr Comp Biol 57:988–998. https://doi.org/10.1093/icb/icx032

Bueno AF, Sosa R, Corrêa Ferreira BS, Moscardi F, Bueno F (2012). Inimigos naturais das pragas da soja. In: Hoffmann-Campo CB, Corrêa-Ferreira BS, Moscardi F. (ed) Soja manejo integrado de insetos e outros artrópodes-praga. 1st edn. Embrapa, Brasília, pp 493–630

Carvalho GDS, Silva LB, Reis SS, Veras MS, Carneiro E, Almeida MLD, Lopes GN (2017) Biological parameters and thermal requirements of *Trichogramma pretiosum* reared on *Helicoverpa armigera* eggs. Pesq Agropecu Bras 52:961–968. https://doi.org/10.1590/S0100-204X2017001100001

Coelho A Jr, Stouthamer R, Parra JRP (2019) Flight propensity of isofemale lines of *Trichogramma pretiosum* Riley in two relative humidity levels. Fla Entomol 101:364–368. https://doi.org/10.1653/024.101.0325

Coutinho CR, Souza SA, Pontes ADS, Godoy MS, Pereira FF, Pastori PL (2021) Thermal requirements of *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) lines in *Neoleucinodes elegantalis* (Lepidoptera: Crambidae) eggs. Rev Colomb Entomol 47. https://doi.org/10.25100/socolen.v47i1.8548

Davies AP, Carr CM, Scholz BC, Zalucki MP (2011) Using *Trichogramma* westwood (Hymenoptera: Trichogrammatidae) for insect pest biological control in cotton crops: an Australian perspective. Aust J Entomol 50:424–440

Figueiredo MDL, Cruz I, Da Silva RB, Foster JE (2015) Biological control with *Trichogramma pretiosum* increases organic maize productivity by 19.4%. Agron Sustain Dev 35:1175–1183. https://doi.org/10.1007/s13593-015-0312-3

Firake DM, Khan MA, Trand M (2014) Alternating temperatures affect the performance of *Trichogramma* species. J Insect Sci 14:1–14. https://doi.org/10.1673/031.014.41

Haddad ML, Parra JRP, Moraes RCB (1999) Métodos para estimar os limites térmicos inferior e superior de desenvolvimento de insetos. FEALQ, Piracicaba

Institute SAS (2011) Statistical analysis system: getting started with the SAS learning. SAS Institute, Cary, NC, USA

Maia AHN, Luiz AJB, Campanhola C (2000) Statistical inference on associated fertility life table parameters using jackknife technique: computational aspects. J Econ Entomol 93:511–518. https://doi.org/10.1603/0022-0493-93.2.511

Nava DE, Takahashi KM, Parra JRP (2007) Linhagens de Trichogramma e Trichogrammatoidea para controle de Stenoma catenifer. Pesq Agropec Bras 42:9–16. https://doi.org/10.1590/S0100-204X200700010000

Oliveira CM, Oliveira JV, Barbosa DRS, Breda MO, França SM, Duarte BLR (2017) Biological parameters and thermal requirements of *Trichogramma pretiosum* for the management of the tomato fruit borer (Lepidoptera: Crambidae) in tomatoes. Crop Prot 99:39–44. https://doi.org/10.1016/j.cropro.2017.04.005

Oliveira RCM, Pastori PL, Coutinho CR, Juvenal SO, Aguiar CVS (2019) Natural parasitism of *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) in *Neoleucinodes elegantalis* (Lepidoptera: Crambidae) eggs on tomato (Solanales: Solanaceae) in the Northeast region, Brazil. Braz J Biol 80:474–475. https://doi.org/10.1590/1519-6984.206676

Parra JRP (2014) Biological control in Brazil: an overview. Sci Agric 71:420–429. https://doi.org/10.1590/0103-9016-2014-0167

Parra JRP, Coelho A Jr (2022) Insect rearing techniques for biological control programs, a component of sustainable agriculture in Brazil. Insects 13:105. https://doi.org/10.3390/insects13010105

Parra JRP (2021) Elaboração de programas de controle biológico: uma visão inter e multidisciplinar. In: Parra, JRP; Pinto, AS; Nava DE; Oliveira, CR; Diniz, AJF (Org.). Controle biológico com parasitoides e predadores na agricultura brasileira. 1ed. Piracicaba: Fealq 1: 39–54.

Parra JRP, Coelho Jr A (2019) Biological control applied in Brazil; from laboratory tests to field application. J Insect Sci 19. https://doi.org/10.1093/jisesa/iey112

Parra JRP, Coelho Jr. A (2021) *Trichogramma* spp. um caso de sucesso de controle biológico aplicado no Brasil. In: Parra, JRP; Pinto, AS; Nava DE; Oliveira, CR; Diniz, AJF (Org.). Controle biológico com parasitoides e predadores na agricultura brasileira. 1ed. Piracicaba: Fealq 1:203–234

Pereira FF, Barros R, Pratissoli D, Parra JRP (2004) Biologia e exigências térmicas de *Trichogramma pretiosum* Riley e *T. exiguum* Pinto and Platner (Hymenoptera: Trichogrammatidae) criados em ovos de *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). Neotrop Entomol 33:231–236. https://doi.org/10.1590/S1519-566X2004000200014

Pratissoli F, Oliveira D, Damascena A, Junior LA, Pratissoli D (2021) Parasitismo de *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) em ovos de *Trichoplusia ni* (Lepidoptera: Noctuidae). Enciclopédia Biosfera 18:37

R Development Core Team (2011) R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available at: https://www.r-project.org/.

Ricalde MP, Garcia FRM (2013) Insetos e ácaros associados à cultura da oliveira na América do Sul. Revista De Ciências Ambientais 7:61–72

Scheunemann T, Manica Berto R, Nörnberg SD, Gonçalves RS, Grützmacher AD, Nava DE (2019) Biology and fertility life tables for *Palpita forficifera* (Lepidoptera: Crambidae) reared on three olive cultivars and privet. J Econ Entomol 112:450–456. https://doi.org/10.1093/jee/toy327

Silveira Neto SS, Nakano O, Barbin D, Nova NV (1976) Manual de Ecologia dos Insetos. Editora Agronômica Ceres, São Paulo

Southwood TRE (1995) Ecological methods. Chapmam & Hall, London, p 524

Takahashi TA, Nishimura G, Querino RB, Foerster LA (2021) An integrative taxonomy of a new species of *Trichogramma* Westwood (Hymenoptera: Trichogrammatidae) with high reproductive capacity. Neotrop Entomol 50:90–99. https://doi.org/10.1007/s13744-020-00834-2

Zago HB, Pratissoli D, Barros R, Gondim JR, Santos JR (2007) Capacidade de parasitismo de *Trichogramma pratissolii* Querino and Zucchi (Hymenoptera: Trichogrammatidae) em hospedeiros alternativos, sob diferentes temperaturas. Neotrop Entomol 36:84–89. https://doi.org/10.1590/S1519-566X2007000100010