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ORIGINAL ARTICLE

Efficiency of female age of egg parasitoids on parasitism of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) eggs of various ages

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Abstract

The use of egg parasitoids in the biological control of insect pests is a promising technique in integrated pest management. However, there is little information on the effects of parasitoid female age and host egg age on parasitization rates specifically on the behaviour of the egg parasitoids such as *Trichogramma pretiosum* Riley and *Telenomus remus* Nixon which can have substantial effects on parasitism towards insect pest eggs. Thus, this communication evaluated the relationships between the age of the parasitoid and host egg on the parasitism of *Spodoptera frugiperda* eggs by *T. pretiosum* and *T. remus* in three independent bioassays. In the first and second bioassay, two egg parasitoids (*T. pretiosum* and *T. remus*) females were grouped by age in days (ranging from 1–6 and 1–10 days old for *T. pretiosum* and *T. remus,* respectively) and were offered 100 eggs of *S. frugiperda* per treatment for 24 h separately. In the third bioassay, 100 eggs of *S. frugiperda* of different ages (24, 48 and 72 h old) were offered separately to *T. pretiosum* and *T. remus* females for 24 h. The variables such as the number of eggs parasitized, parasitoid emergence (%) and female progeny were evaluated. The results indicated that as the age of the *T. pretiosum* increases, per cent parasitism and adult emergence decreases but age of *T. remus* females did not affect the number of *S. frugiperda* eggs parasitized or the emergence of the progeny. However, the sex ratio was more male-biased in the progeny of 1- and 2-day-old females compared to older wasps in the case of *T. remus*. In the third bioassay, the highest parasitism was observed in 24- and 48-h-old eggs and the per cent emergence decreased with increasing female age.

Keywords Fall armyworm · Biological control · Egg parasitoid · Parasitism · Adult emergence · Female progeny

Abbreviations

FAW	Fall armyworm
Sp.	Species
viz.	Videre licet (synonym for 'namely')
i.e.	That is
h	Hour
gm	Gram
cm	Centimetre
ml	Millilitre
L	Litre
°C	Degree celsius
RH	Relative humidity
UV	Ultraviolet
MARS	Main Agricultural Research Station
UAS	University of Agricultural Sciences
IPM	Integrated pest management
ABC	Augmentative biological control

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Introduction

The *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) commonly known as fall armyworm (FAW) is originally from tropical and temperate America invaded India in May 2018 (Sharanabasappa et al. 2018a). Immediately after the invasion, it spread rapidly to various regions of Karnataka within a jiffy and rampantly spread to other Indian states (Ganiger et al. 2018; Mahadevaswamy et al. 2018; Shylesha et al. 2018). It has caused harm to a number of crops in India, including maize, sorghum, finger millet and sugarcane (Chormule et al. 2019; Deshmukh et al. 2021a). Nevertheless, maize is a more preferred host and shows an infestation rate of 6–100% in the Indian subcontinent (Mallapur et al. 2018). Deshmukh et al. (2021b) recently reported that the fall armyworm invasion has led to a dramatic upsurge in the usage of pesticides per hectare in both *kharif* and *rabi* seasons in India from US$ 61 5.56 in 2017 to US$ 56.01 in 2020.

The need for this study arises from the invasion of *S. frugiperda* in India as it was found to be the most obliterating pest in terms of causing significant yield loss to several agricultural crops (Knipling 1980). Spraying chemical insecticides is the most widely used weapon in India for managing this pest (Queiroz et al. 2019; Deshmukh et al. 2021b). However, synthetic insecticides pose inherent problems, including negative impacts on non-target organisms and the environment (Fernandes et al. 2010). To negate its ill effects, it is therefore necessary to use more environmentally friendly pest control methods that keep the pest population below the Economic Threshold Level (ETL) (1–2 larvae per whorl or 15–20% whorls damage by young plants, during the first 30 days) without excessive dumping of chemicals (Van Lenteren et al. 2018; Nidhi et al. 2019). Additionally, because of the hiding tendency of larvae, chemical control of this pest becomes too taxing. Therefore, releasing egg parasitoids to manage this pest at the egg stage is a potential tool in conjunction with other control techniques as a component of integrated pest management (IPM).

For the purpose of effectively controlling the pest of the genus *Spodoptera*, a special emphasis on the utilization of *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) and *Telenomus remus* Nixon (Hymenoptera: Scelionidae) at field level is a must (Pomari et al. 2013), owing to their high reproductive potential, effectiveness against the intended pest and these wasps are an excellent choice for augmentative releases (Cave 2000; Sharanabasappa et al. 2019; Firake and Behere 2020; Navik et al. 2021). The performance of parasitoid females of various ages and the behaviour of *T. pretiosum* and *T. remus* towards the FAW embryos, however, are not well understood. In order to provide suitable treatment for FAW, it is crucial to comprehend the information on the age of female egg parasitoids and their capacity to control FAW, this information is very much essential to provide appropriate suggestions and recommendations for using parasitoids in augmentative biological control (ABC) programmes. In addition, to determine the exact timing and also the frequency of parasitoid releases in the field is certainly very important to know how long the parasitoid females of the candidate species can achieve high levels of parasitism during their lifetime. Besides this, the knowledge regarding the preference of females for host eggs of different ages (developmental stages) and of the susceptibility of host eggs to parasitism as a function of age may help to adjust the releases in a timely manner and also to consider the need for repeated releases. The two species of egg parasitoids are considered in this study as they may have different life history strategies that may complement or interfere with each other. Therefore, the prime objective of this study is to assess how the age of the parasitoid and host egg influenced the parasitization process and the emergence of adult parasitoids, as well as the sex ratio of the parasitoid offspring.

Methods

Study site

The insect cultures maintenance and lab studies were carried out at Biocontrol laboratory, Main Agricultural Research Station, UAS, Raichur (16° 20′ 15.26″ E and 77° 32′ 56.46″ N) under the growth chamber with a temperature range of 25–26 °C, relative humidity of 70–75% and on a 14:10 h L:D photo regime. The rainy season in this agro-ecosystem lasts from the middle of July to the middle of December, with a unimodal rainfall trend.

Host and parasitoid rearing

In this study, FAW eggs and adult females of *T. pretiosum*, and *T. remus* were used. The protocols mentioned and methodology described by Sharanabasappa et al. (2018b) and Silva and Parra (2013) for *S. frugiperda*, Tefera et al. (2019) for *T. pretiosum* and Bueno et al. (2008) for *T. remus* were employed to rear and maintain the cultures under regulated laboratory conditions for the successful conduct of the experiment.

Maintenance of host, *Spodptera frugiperda*

The field collected larvae were transferred to the laboratory in individual plastic vials (to avoid cannibalism) which were arranged in labelled trays with dimensions of 38 cm × 26 cm × 6 cm in a growth chamber. Fresh maize leaves were given to early instars (up to 4–5 days) and freshly prepared artificial diet (Jaba et al. 2020) to later instars (5th day and on) every day until pupation (Silva and Parra 2013). Newly formed healthy pupae were gathered and sexed as male and female based on their genital structures and kept apart in plastic containers covered with muslin cloth for the moth emergence.

After the emergence (8–10 days), the adults (5 pairs/jar) were introduced into an oviposition jar (3000 ml) where paper strips (15 × 21 cm) provided were served as an oviposition substrate along with cotton swabs soaked in 50%

honey solution fortified with 1–2 drops of multivitamin, 1.2 gm ascorbic acid and 0.2 gm methyl parahydroxybenzoate per 200 ml served as an adult food to enhance the fecundity and egg fertility. Every alternate day, a fresh honey swab was provided to adults as feed inside the jar, which was covered with muslin cloth and secured with a rubber band. The conduction of the experiment and culture maintenance was carried out using the egg masses. Hatched neonate larvae were transferred into a plastic box (20 × 10 cm) and kept for further culture maintenance using fresh maize leaves (Sharanabasappa et al. 2018b).

Rearing of *Trichogramma pretiosum*

The freshly collected and cleaned *Corcyra* (Lepidoptera: Pyralidae) eggs were used for preparing the tricho-cards (15 × 7.5 cm). Cards were made by smearing 2% glue (starch-based locally available Camalin gum) and evenly sprinkling 1 cc of *Corcyra* eggs over them with the aid of a sieve. To kill the embryo, these cards were subjected to UV-rays of 15 W for a time span of 10–15 min. In order to parasitize the freshly prepared cards, they were introduced to freshly emerged mother card (freshly emerged adults) in a jar of 3 L capacity for a duration of 24 h. Adults were given 50% diluted honey streaks inside the container as feed. For every 24 h, fresh egg cards were provided for parasitisation by replacing the old ones, this process was continued for 3–4 days. Thus, obtained cards were used for further maintenance of parasitoid culture as well as for experimental purposes (Tefera et al. 2019).

Rearing of *Telenomus remus*

Spodoptera frugiperda egg masses (0–24 h old) were used to rear *T. remus* by pasting them on to a cardboard sheet (10 × 2 cm) using 2% gum and were placed inside the glass tubes (15 × 2.5 cm) containing eggs that had already been parasitized by *T. remus*. To feed the adult parasitoids soon after their emergence, a tiny cotton swab piece was stuck to the glass tube's side which was dipped in 5% honey solution. The mouth of the glass tubes was sealed with cotton plugs and adults were then permitted to parasitize for 24 h (freshly emerged parasitoid females were not used for any treatments, only after 24 h of their emergence they were taken for experiments).

For every 24 h, *T. remus* adults were provided with fresh egg cards for parasitisation by replacing the old ones. In 4–5 days, the majority of the parasitized eggs turned black in colour. The larvae that hatched and emerged from unparasitized eggs were scored out and removed. Cards that contained only parasitized eggs were moved into fresh, clean tubes to allow the parasitoids to emerge. The adult parasitoids that emerged within 9–10 days, with the males typically emerging before the females. Of the adult parasitoids emerged, 10% were kept for future culture maintenance (Bueno et al. 2008).

Parasitism of *S. frugiperda* eggs by *T. pretiosum* and *T. remus* females of different ages

The freshly collected UV-irradiated (10–15 min) *S. frugiperda* eggs (24 h old) were pasted randomly on a small white paper card smeared with a gum diluted in deionised water in order to prepare egg cards (2 × 1 cm) that could be used to study the effects of female parasitoids age of *T. pretiosum* and *T. remus* on parasitism and adult emergence of host eggs (each card contains 20 eggs). The egg cards were individually placed in a glass vial with a single adult female of a different age in each vial. After 24 h, the parasitoids were removed, and the vials holding the parasitized egg cards were kept in the controlled growth chamber. At each and every stage of parasitoid development, observations on the percentage of parasitism and adult emergence were taken. Five replications for each age of the female parasitoid were used in the experiment, which was arranged in a completely randomized manner (ranging from 1–6 and 1–10 days old for *T. pretiosum* and T. *remus*, respectively, of the same laboratory generation). Adults in all treatments received diluted honey as food during the trial (Queiroz et al. 2017).

By counting the overall number of eggs in each egg mass as well as the number of eggs that turned black to show parasitism, the percentage of parasitism was calculated and expressed in percentage.

The number of adults that emerged from the overall number of parasitized host eggs were counted on the basis of the emergence hole and the percentage of adult emergence of egg parasitoids was calculated using the formula:

$$= \frac{\text{Number of parasitoid adults emerged}}{\text{Total number of parasitized eggs}} \times 100$$

Egg cards were made in the same manner as previously described and exposed to newly emerged parasitoid females of *T. pretiosum* and *T. remus* for 24 h separately in order to determine the sex ratio. The adults that emerged from those eggs were left until their death. These deceased adults were observed under the microscope (Nikon SMZ 745) to determine their sex based on the characteristics of their antennae. Males of *T. pretiosum* and *T. remus* have filiform, more plumose antennae with long black hairs and they are smaller than females (Oktaviani and Pudjianto 2021; Laurentis et al. 2019). In both instances, the females were typically larger than the males, with a tapering abdomen and clubbed antenna, less plumage and short bristles.

Effect of host egg age on per cent parasitism and adult emergence of *T. pretiosum* and *T. remus*

Egg cards were made using freshly collected UV-irradiated FAW eggs of various age groups, i.e., 24, 48, and 72 h old and kept separate to investigate the impact of different ages of host eggs. Twenty UV-irradiated eggs from each card (same age group) were placed singly in glass vials (8 × 2 cm) each holding a single adult female (aged 24 h) of the two distinct egg parasitoids separately. After 24 h, the cards were taken out and notes on the percentage of parasitism and adult emergence at each age group of host eggs and for two different egg parasitoids were made. The experiment had five replications for each age group of eggs and egg parasitoids and it was set up in a completely randomized design (CRD) pattern. Adults in all treatments received diluted honey as food during the trial (Laurentis et al. 2019).

The *T. pretiosum* and *T. remus* culture have been obtained from ICAR-National Bureau of Agricultural Insect Resources, Bengaluru and voucher specimens were deposited in the Department of Agricultural Entomology, UAS, Raichur.

Statistical analysis

The data were subjected to a one-way analysis of variance (ANOVA), and the Tukeys test was used to distinguish between the means. Prior to the per cent transformation for ANOVA, the percentage values were transformed, and SPSS software was used for all statistical analysis (SPSS version 21.0).

Result

Effect of age of female parasitoid, *T. pretiosum* on *S. frugiperda* eggs

The age of female parasitoids significantly influenced their parasitism and adult emergence rates, with younger parasitoids being more effective. The per cent parasitism and adult emergence by female parasitoids was highest on day 1 (98.00% and 98.97%) and gradually decreased with increasing age, reaching the lowest at day 6 (22.00% and 31.81%). The differences in parasitism and adult emergence among different age groups were statistically significant ($p < 0.001$). However, the sex ratio of the emerging parasitoids remains relatively consistent regardless of the female parasitoid's age, with values ranging from 0.70 to 0.73. No significant differences in sex ratio were observed ($p = 0.00$) (Table 1).

Effect of age of female parasitoid, *T. remus* on *S. frugiperda* eggs

The percentage of parasitism and adult emergence were unaffected by the female *T. remus* age (Table 2). The parasitism rate varied from 57.00 ± 1.22 to 83.00 ± 1.22 per cent, reaching its peak at six days of age (83.00 ± 1.22%). The lowest parasitism rate was recorded at three days of age (57.00 ± 1.22%). The adult emergence rate ranged from 93.24 ± 2.11 to 98.79 ± 1.17 per cent, the highest was (98.79 ± 1.17%) at six days. The percentage of females produced by parasitism of 1- and 2-day-old *T. remus* females was lower (0.64 ± 0.33 and 0.66 ± 0.33, respectively) than compared to progeny from 5-day-old females (0.85 ± 0.04), indicating that the age of wasps had an impact on parasitoid female progeny. The other treatments, on the other hand,

Table 1 Influence of the age of the female parasitoid, *Trichogramma pretiosum* on per cent parasitism, adult emergence and female progeny on the eggs of *Spodoptera frugiperda* under laboratory conditions

Female parasitoid age (days)	Parasitism (%)	No. of adults emerged	Adult emergence (%)	Sex ratio (female proportion)
1	98.00 ± 1.22a	97.00	98.97 ± 1.20a	0.70 ± 0.031a
2	97.00 ± 2.00a	94.00	96.90 ± 1.87ab	0.73 ± 0.023a
3	82.00 ± 2.55b	73.00	89.02 ± 1.22c	0.73 ± 0.013a
4	56.00 ± 1.87c	42.00	75.00 ± 1.22d	0.71 ± 0.019a
5	49.00 ± 1.87d	25.00	51.02 ± 1.58e	0.72 ± 0.032a
6	22.00 ± 1.22e	07.00	31.81 ± 1.22f	0.71 ± 0.016a
Df (error)	24	24	24	24
F value	86.35	–	35.40	0.33
P-value	< 0.001	–	< 0.001	0.00

Means ± Standard error of mean (SEM) followed by the same letter within a column did not differ statistically (one-way ANOVA, Tukey test $p \geq 0.05$). Sex ratio = number of females/ (number of males + females). NS—ANOVA not significant. Number of eggs offered per treatment—100 and number of replications per treatment—05

Table 2 Influence of the age of the female parasitoid, *Telenomus remus* on per cent parasitism, adult emergence and female progeny on the eggs of *Spodoptera frugiperda* under laboratory conditions

Female parasitoid age (days)	Egg parasitism (%)	No. of adults emerged	Adult emergence (%)	Sex ratio (Female proportion)
1	69.00 ± 1.87c	67.00cde	97.10 ± 1.82	0.64 ± 0.03
2	66.00 ± 1.91c	63.00e	95.45 ± 1.80	0.66 ± 0.03
3	57.00 ± 1.22d	54.00f	94.73 ± 2.17	0.72 ± 0.03
4	74.00 ± 1.85b	71.00bc	95.94 ± 1.64	0.80 ± 0.06
5	70.00 ± 1.58bc	68.00cde	97.14 ± 1.82	0.85 ± 0.04
6	83.00 ± 1.22a	82.00a	98.79 ± 1.17	0.82 ± 0.013
7	80.00 ± 1.58a	76.00b	95.00 ± 2.34	0.68 ± 0.012
8	74.00 ± 1.87b	69.00cd	93.24 ± 2.11	0.76 ± 0.019
9	79.00 ± 1.77a	76.00b	96.20 ± 1.54	0.81 ± 0.010
10	68.00 ± 1.22c	64.00de	94.11 ± 1.46	0.75 ± 0.015
Df (error)	40	40	40	40
F value	22.71	32.30	0.776	5.926
P-value	0.000	0.000	NS	0.000

Means ± Standard error of mean (SEM) followed by the same letter within a column did not differ statistically (one-way ANOVA, Tukey test $p \geq 0.05$). Sex ratio = number of females/ (number of males + females). NS—ANOVA not significant. Number of eggs offered per treatment—100 and number of replications per treatment—05

were identical and at par with another and all had a sex ratio that was greater than 0.60.

The impact of host egg age on per cent parasitism and adult emergence of *T. pretioum* and *T. remus*

The age of the host eggs exerted a significant influence on both the percentage of parasitism and adult emergence of *T. pretiosum* and *T. remus*. Specifically, when parasitizing 24-h-old eggs, *T. pretiosum* and *T. remus* achieved high parasitization rates of 97.00 ± 1.22% and 67.00 ± 1.00%, respectively, which were comparable to those observed with 48-h-old eggs (95.00 ± 1.58% and 64.00 ± 2.92%). However, eggs that were 72 h old exhibited the lowest percentage of parasitism, with rates of 08.00 ± 1.26% for *T. pretiosum* and 21.00 ± 1.26% for *T. remus*. This trend was similarly reflected in the emergence of adults for both *T. pretiosum* and *T. remus* (Table 3).

Discussion

The study conducted on optimum age of the female to get maximum parasitization with healthy sex ratio helps the commercial mass producing entrepreneurs/insectaries for maximum mass production of F_1 generations. As it throws a light on comparative performance between egg parasitoid species helps in selection of suitable species for the effective management of *S. frugiperda* under the field conditions. The results clearly indicated that as the age of the parasitoid increases, per cent parasitism and adult emergence decreases. However, the present findings contradict

Table 3 Impact of host egg age on per cent parasitism and adult emergence of egg parasitoids on *Spodoptera frugiperda* under laboratory conditions

Host egg age (h)	Total no. of eggs offered	*T. pretiosum*		*T. remus*	
		Parasitism (%)	Emergence (%)	Parasitism (%)	Emergence (%)
24	100	97.00 ± 1.22a	98.96 ± 2.23a	67.00 ± 1.00a	97.01 ± 4.10a
48	100	95.00 ± 1.58a	96.42 ± 6.51a	64.00 ± 2.92a	96.87 ± 2.23a
72	100	08.00 ± 1.26b	0.00 ± 0.00b	21.00 ± 1.26b	90.47 ± 2.73b
Df (error)		12	12	12	12
F value		2582.33	801.65	180.63	2.64
P-value		0.000	0.000	0.000	0.001

Means ± Standard error of mean (SEM) followed by the same letter within a column did not differ statistically (one-way ANOVA, Tukey test $p \geq 0.05$). Sex ratio = number of females/ (number of males + females). NS—ANOVA not significant. Number of eggs offered per treatment—100 and number of replications per treatment—05 the results of Queiroz et al. (2020) who studied the influence of the age of *T. pretiosum* females on parasitism of *A. gemmatalis* eggs and reported that the numbers of eggs parasitized and parasitoids that emerged were unrelated to the age of *T. pretiosum* females but the sex ratio was higher for 5-day-old females, which might be due to ability to adjust egg production according to host availability.

The findings of the present study are consistent with those of Queiroz et al. (2019), who examined the parasitism of *S. frugiperda* eggs by *T. remus* females of various ages (1–10 days) and found that neither the number of *S. frugiperda eggs* parasitized nor the appearance of the progeny were impacted by the age of *T. remus* females. In contrast to elder wasps, the sex ratio was more skewed towards males in the offspring of 1- and 2-day-old females. The ability to escape superparasitism and the capacity to hold onto eggs even in the absence of hosts may be the cause.

The findings of the current investigation into the impact of host egg age are in line with those of Hutchison et al. (1990), who found that *Trichogrammatoidea bactrae* prefers to oviposit on eggs that are 24 h old as opposed to older eggs when it is raised on pink bollworm eggs. In a laboratory study by Laurentis et al. (2019), the impact of host egg age (i.e., 1-, 2-, 3-, and 4-day-old eggs) on *T. pretiosum* parasitism was examined on *C. cephalonica* eggs. It was found that the parasitism rate was lower on 2-day-old eggs (63.3%) than host eggs of other ages. Similar to this, Sultan et al. (2013) investigated the impact of host egg age (24, 48, and 72 h old) on the parasitism of *T. chilonis* reared on *Sitotroga cerealella* eggs and found that adult emergence and parasitism were highest on eggs that were 24 h old (79.40 and 76.50%), followed by eggs that were 48 h old (59.40 and 52.30%), with no significant differences in the female progeny. According to Queiroz et al. (2020), who investigated the influence of host egg age (24, 48, and 72 h old) on the parasitism of *T. pretiosum* reared on *A. gemmatalis* eggs, the number of eggs parasitized was highest on eggs of 24 h, followed by eggs of 48 h. These results are consistent with other studies.

The factor contributing to the high ability of *T. remus* to parasitize *S. frugiperda* egg masses is the species' high female fecundity and reproductive efficiency (Agboyi et al. 2021). Similar to how *T. remus* parasitized noticeably more eggs, it has a higher fecundity rate and is bigger and more robust than trichogrammatids, allowing it to parasitize more eggs (Laminou et al. 2020).

Trichogrammatids are typically diminutive, with a smaller ovipositor. Due to the mature/well-developed embryos and reduced fecundity rate/reproductive capacity compared to *T. remus*, 72-h-old eggs had thicker chorion, making penetration and oviposition more challenging. Trichogrammatiods prefer to parasitize younger FAW eggs, which may improve the survival of their offspring or make host eggs easier to parasitize. Changes in the external and internal features of the eggs are likely what reduces parasitism as host egg development advances. The surface, size, chorion structure, and other characteristics of eggs from different age groups may vary, as well as other traits like a change in colour during embryonic development and hardening of the chorion during embryonic development, which restricts the ability of the female parasitoid ovipositor to penetrate the egg. Additionally, as a host embryo develops, its nutritional worth decreases, which may cause the egg parasitoids to show less preference for it.

Conclusion

The current research, to the best of our knowledge, is the first to describe the biological traits of *T. pretiosum* and *T. remus* on *S. frugiperda* eggs in India and their potential significance for a successful application in biological management. The results indicated that as the age of the *T. pretiosum* females increased, both the per cent parasitism and adult emergence decreased but it is not same in the case of *T. remus*. The age of the host eggs increased, the percentage parasitism decreased significantly. These findings are valuable for both optimizing field releases of the parasitoids for the biological control of *S. frugiperda* and keeping the quality standard of *T. pretiosum* and *T. remus* or egg parasitoids in the laboratory. *Telenomus remus* appears to be more effective in parasitizing *S. frugiperda* eggs, possibly due to higher fecundity. *T. pretiosum*, on the other hand, showed a decline in efficiency with age, indicating that timely releases of young parasitoids might be more effective. Comprehensively, the results suggest that *T. pretiosum* and *T. remus* can be more promising candidates for augmentative release against fall armyworm. However, there is a barrier to the use of *T. remus* on large-scale release, because it would increase costs, since the *Spodoptera* rearing is more costly and complex than rearing alternative hosts used for *Trichogramma* spp. Hence, researchers suggest the field release of *T. pretiosum*. The knowledge of the biological characteristics of these parasitoids, as well as their preferences for host egg age and the age of their own females, can help to promote their use in integrated pest management. However, further studies and field experiments are indeed essential to validate these findings and develop practical guidelines for the utilization of these egg parasitoids in pest management programmes.

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Author contributions AH, PA, SH and MK: conceptualization and manuscript editing, VK: experimentation, original data collection and draft writing, VK and AH: data curation, SSD: manuscript reviewing and editing. All authors read and approved the final manuscript.

Declarations

Conflict of interest No conflict of interest was reported by the authors.

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