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Studies of certain parameters affecting two parasitoid species, *Trichogramma evanescens* Westwood and *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae), on egg host, *Sitotroga cerealella* (Olivier) (Gelechiidae: Lepidoptera)

Esraa M. Abdel Halim[1], Mona R. El-Mandarawy[1*], Magda H. Naroz[2] and Sayeda S. Ahmed[2]

Abstract

Background Two *Trichogramma* spp., *Trichogramma evanescens* Westwood and *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae), were studied to control one of the most cereal pests attacking various grains, *Sitotroga cerealella* (Olivier) (Gelechiidae: Lepidoptera). Experiments were carried out to evaluate *S. cerealella* egg-ages, parasitoids' emergence time and cold storage host eggs on rearing the two tested parasitoids' spp.

Results The age of *S. cerealella* eggs had significantly influenced the parasitization and adult emergence rates of the two parasitoid species. Parasitism rate resulted from old host eggs (32 h old) (44.93%) decreased than those of the fresh ones (2 h old) (95.85%). Emergence rate ranged between (62.64–97.85%) for *T. evanescens* and (62.90–95.54%) for *T. bactrae* from different *S. cerealella* egg-ages (0–32 h). Regardless to late emerged parasitoids, their population affected. *T. evanescens* parasitized rate ranged (73.79–95.06%), which comparatively lower than those of *T. bactrae* (88.81–96.90%), at parasitoid emerging times (0–64 h), respectively. Emergence times had significantly differences in the emergence rate of *T. evanescens* and/or *T. bactrae*. On the other hand, percentage of parasitism of the non-stored *S. cerealella* eggs was higher than the other cold-stored ones. The emergence rate of adult parasitoids, *T. evanescens* (66.00–91.16%) and *T. bactrae* (71.16–94.11%), was decreased at the cold storage durations (5–40 days) increased. In comparison to the tested biological aspects between the two parasitoid species, non-significant differences were recorded, at the three assessment parameters, which include host egg-ages, parasitoid emergence time and cold-stored eggs. Meanwhile, there were significant differences between F1 emerged rates for *T. evanescens* and *T. bactrae* obtained at each of the three tested parameters.

Conclusion It was concluded that low emergence time of the parasitoids, *T. evanescens* and *T. bactrae*, was relatively more effective when they parasitized the fresh egg-age and less cold storage periods of *S. cerealella*.

Keywords *Trichogramma evanescens*, *Trichogrammatoidea bactrae*, *Sitotroga cerealella*, Host egg-age, Parasitoid emergence time, Cold-stored host eggs, F1 emergence parasitoids

*Correspondence:
Mona R. El-Mandarawy
melmandarawy@gmail.com
Full list of author information is available at the end of the article

Background

Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Gelechiidae: Lepidoptera), is one of the most cereal pests that attacks various grains such as wheat, corn, barley and rice (Salim et al. 2023). The larvae as a destructive stage cause infestation and damage to field crops and an additional damage to grains after harvest (Kumar et al. 2022). Jena et al. (2023) indicated that infested seeds are usually unable to germinate where significant quantitative and qualitative economic losses, decrease in the weight and nutritional value of the grains were estimated. *S. cerealella* causes an internal infestation of grains, so it is difficult to be controlled with usual chemical pesticides, adding to the risks of uses pesticides.

Biological control, especially parasitoids, is considered one of the most successful controlling methods against stored grain pests (Tripathi 2018). Genus *Trichogramma* (Hymenoptera: Trichogrammatidae) as a biological control agent presented natural enemies for many of the stored grain moths (Flinn and Schöller 2012). *Trichogrammatoidea bactrae* Nagaraja and *Trichogramma evanescens* Westwood are common egg parasitoid species, which is extremely important in controlling cereal pests to prevent the damage from entering larvae into grains.

Certain biological aspects affect the effectiveness and ability of the *Trichogramma* parasitoids to parasitize. The host age is one of the most factors affected parasitism and parasitoid's ability to parasitize. Parasitoids showed a strong preference for young host eggs compared to older ones (Perveen et al. 2012). Developmental period of female parasitoids increases without the presence of a host and minimizes the ability to parasitize (Ksentini et al. 2018).

The objective of the present study was to evaluate different biological aspects on rearing of two tested parasitoid species, *T. evanescens* and *T. bactrae*: as the effect of host egg-ages, the old of parasitoids' emergence and the cold storage of *S. cerealella* eggs.

Methods

Rearing of *Sitotroga cerealella*

The mass rearing of *S. cerealella* was under controlled temperature of 28 ± 1°C and 65 ± 5% RH. Wheat grains boil and then spread to left them dry. Dried wheat grains were placed into wire trays (6kg wheat grains /tray). The wheat grains were infested with *S. cerealella* eggs by homogenously sprinkled on trays (1 g eggs/1 kg wheat grains) placed in horizontal positions. After 10 days later, wire trays were placed vertically in cages, and then, after 25–30 days, *S. cerealella* moths started to emerge and falling in plastic jars fitted under each cage. Daily, moths were collected into wire cylinders and new plastic jars replaced daily. Wire cylinders filled with moths were replaced in a device till the moth's eggs extracted to use fresh or stored ones at 8°C.

Rearing of *Trichogramma* spp. parasitoids

Two parasitoid species, *T. evanescens* and *T. bactrae*, were used. *T. bactrae* was imported from an American University, by Dr. A. H. El Heneidy (Plant Protection Research Institute, ARC) and adapted under Egyptian natural conditions. The mass rearing of the 2 *Trichogramma* spp. was prepared by gluing *S. cerealella* eggs < 24 h old on hard paper cards (9 × 13cm), and then, the host egg cards were introduced into plastic jars for exposing newly emerged (< 24 h) to *Trichogramma* adults. Afterward, the parasitized egg cards were removed and other fresh ones were replaced. The jars were maintained at 27°C.

Experiments

Effect of host egg-ages on the rearing of two parasitoid spp. *T. evanescens* and *T. bactrae*

Five different ages of *S. cerealella* eggs (0, 2, 4, 8, 16 and 32 h.) were studied. Each age of host eggs was glued on cards, introduced individually into 250 ml plastic jars, each containing male/female pairs of freshly emerged parasitoid adults (< 24 h.). Jars were covered with cloth-wrapped cotton. Experiments were repeated in 4 replicates for each age. The total number of parasitized and emergence of the parasitoid species was recorded and their percentages calculated. Also, the parasitoids' developmental periods at each age of host eggs were studied.

Effect of parasitoids' emerging time on *Trichogramma* spp. parasitism

The experiment was carried out at 27 ± 1°C and 60 ± 5 RH. Hard paper cards (1 × 1cm), contained glued *S. cerealella* eggs (< 24 h. old), were exposed to each of the parasitoid adults of *T. evanescens* and *T. bactrae* and then waited until the hatching of the newly emerged parasitoids. Paper cards with different ages of parasitoids' adults (0, 4, 8, 16, 32 and 64 h.) were transferred, each to a new plastic jar. Each emergence time was repeated in 4 replicates. Parasitism rate and emerging rate were calculated.

Effect of cold storage *S. cerealella* eggs on *Trichogramma* spp. parasitism

Eggs of *S. cerealella* were incubated at 8 °C to 5, 10, 20 and 40 days. Eggs (> 24 h.) were used as control. Cold-stored eggs, at each period of storage and those of control, were placed on square paper card covered with a thin layer of glue and then tested by exposing them separately to each of the two *Trichogramma* parasitoids at 27 ± 1°C and 60 ± 5 RH. Four replicates were carried out per test. Parasitized eggs were incubated at 27 ± 1°C and 60 ± 5 RH. The number of parasitized eggs (blackened

host eggs) was recorded in each treatment. Percentage of emerged adults was calculated: Number of emerged adults/N number of parasitized eggs × 100.

F1 progeny of *T. evanescens* and *T. bactrae*

F1 progeny of *T. evanescens* and *T. bactrae* was obtained from the previous 3 experiments as the same way of each one was studied. Parasitoid adults exposed to a paper card (1 × 1 cm) with *S. cerealella* eggs (> 24 h.) into a plastic jar and waited until the newly emerged adults of parasitoid species. Four replicates were carried out per test for experiment. The number of emerged adults was recorded and the correspondence percentage calculated.

Statistical analysis

Based on the data of percentage of parasitism, an emergence for each parasitoid sp. was analyzed using of one-way ANOVA and means were compared using Duncan test. The LSD test compared between percentage of significant results was used at $P < 0.05$. T test analysis of variance was used to analyze the biological aspects' data between the two parasitoid spp. (at $P < 0.05$).

Results

Effect of host egg-ages on the cultures of the two parasitoid spp., *T. evanescens* and *T. bactrae*

Rate of parasitized eggs (RP)

Parasitization was recorded for blackened eggs due to the deposition of black stain in their inner surface. The age of *S. cerealella* influenced the parasitization rate of the two parasitoid spp. Parasitization of newly collected host eggs (> 24 h.) (control) was significantly higher than any of the other egg-ages. Parasitism rate of old host eggs (32 h old) (44.93%) decreased than those of fresh ones (2 h old) (95.85%) (F = 29.7426, $P > 0.0001$, df = 5, LSD5% = 10.5703) (F = 14.9537, $P > 0.0001$, df = 5, LSD5% = 13.8463) after exposing to *T. evanescens* and *T. bactrae*, respectively. This expected that old host eggs were less preferable for parasitoids to complete their development (Table 1).

Rate of emerged adults (RE)

Out of parasitized eggs, the number of emerged parasitoid adults was counted and their percentages were determined. Parasitoid emergence rate ranged between (62.64–97.85%) for *T. evanescens* and (62.90–97.13%) for *T. bactrae* as a result of different *S. cerealella* egg-age (0–32 h.). This rate was varied significantly (F = 46.2514, $P < 0.0001$, df = 5, LSD5% = 5.9554) and (F = 12.1956, $P > 0.0001$, df = 5, LSD5% = 10.9192) for the two parasitoid

Table 1 Parasitoids, *Trichogramma evanescens* and *Trichogrammatoidea bactrae*, reared on different ages' eggs of the host insect, *Sitotroga cerealella*

S. cerealella old eggs (hrs.)	No. exposed eggs	No. parasitized eggs	% parasitism	No. emerged parasitoid adults	% of emergence	Developmental period (Days)
Trichogramma evanescens						
Control*	762.25	729.25 ± 55.66	95.85 a	713.50 ± 54.11	97.85 a	7.25 ± 0.25
2	392.25	358.75 ± 65.60	91.52 a	338.00 ± 53.92	95.17 a	7.50 ± 0.29
4	496.25	443.25 ± 23.38	89.48 a	382.00 ± 17.74	86.28 b	7.50 ± 0.29
8	370.50	283.00 ± 31.61	77.87 b	226.75 ± 26.03	80.04 c	7.50 ± 0.29
16	847.00	548.75 ± 23.76	65.48 c	390.75 ± 15.99	71.60 d	7.50 ± 0.29
32	429.50	190.00 ± 13.42	44.93 d	119.00 ± 8.57	62.64 e	7.25 ± 0.25
L.S.D.5%			10.5703		5.9554	
Trichogrammatoidea bactrae						
Control*	738.75	721.00 ± 9.77	97.64 a	700.00 ± 4.71	97.13 a	8.75 ± 0.25
2	687.00	646.75 ± 60.62	94.08 a	615.00 ± 47.38	95.54 a	8.75 ± 0.25
4	609.50	553.50 ± 63.15	91.16 ab	509.25 ± 46.64	90.95 ab	8.75 ± 0.25
8	690.75	543.50 ± 23.61	79.19 bc	460.50 ± 22.93	84.75 b	8.50 ± 0.29
16	739.75	487.00 ± 9.34	69.23 c	377.50 ± 26.88	77.81 c	8.50 ± 0.29
32	488.75	245.75 ± 14.33	50.45 d	154.50 ± 14.09	62.90 d	8.75 ± 0.25
L.S.D.5%			13.8463		10.9192	

Control* = > 24h

% followed by the same letters do not differ significantly at P < 0.05 (L.S.D. test)

spp. (*T. evanescens* and *T. bactrae*, respectively), obtained from different host egg-ages (Table 1).

Developmental periods of parasitoid adults (DP)

Total developmental period was counted from parasitoids exposed to host eggs till their emergence. Developmental time of parasitoids was non-significantly varied between hot egg-ages, but longer in older eggs than in younger ones. The developmental period of *T. evanescens* and *T. bactrae* was ranged between (7.25 ± 0.25–7.50 ± 0.29 days) and (8.50 ± 0.25–8.75 ± 0.29 days), respectively, for tested host egg-ages (0–32 h) at 27 ± 1°C (Table 1).

Effect of parasitoids' emerging time on *Trichogramma* spp. parasitism

Rate of parasitized eggs (RP)

S. cerealella eggs parasitized by *T. evanescens* with a parasitism rate ranged (73.79–95.06%), which was comparatively lower than those by *T. bactrae* (88.81–96.90%), for parasitoid emerging time (0–64 h.), respectively (Table 2). There were significant differences between parasitism percentage at the tested emergence time of *T. evanescens* (F = 7.1902, *P* > 0.0007, df = 5 LSD5% = 8.1697) or for *T. bactrae* (F = 4.4252, P > 0.0084, df = 5 LSD5% = 4.2342).

Rate of parasitized eggs (RP)

Emergence time (4–64 h.) had significant differences on the rate of emerged parasitoids. The emergence rate was gradually decreased as the emergence time increased. The highest emergence rate was obtained at 4 h. of emerged *T. bactrae* (90.92%) as compared to (88.45%) of *T. evanescens* at the same emerged time. It decreased to make the lowest rates 70.00 and 72.94% for *T. evanescens* and *T. bactrae*, respectively, at 64 h. of emergence (Table 2).

Developmental periods (DP)

T. evanescens lived about (7.25–8.50 days) for parasitoid emerging times (0–64 h.); however *T. bactrae* reared (8.50–8.75days) for the same tested parasitoid emerging times at 27 ± 1 °C (Table 2). Non-significant differences of parasitoids lifespan were found among times' emergences.

Effect of cold storage *S. cerealella* eggs on *Trichogramma* spp. parasitism

Rate of parasitized eggs (RP)

Percentage parasitism of the non-stored *S. cerealella* eggs was higher than the other cold-stored ones. Parasitization rate was significantly decreased with increasing the period of host-stored eggs. *T. evanescens* adults caused the highest parasitization rate (93.84%) from the non-cold-stored eggs (0 day). The egg cold storage periods (5, 10, 20 and 40 days) resulted parasitization rates of *T. evanescens* (87.78, 87.50, 79.71 and 61.41%), respectively. In the control, percentage parasitism of *T. bactrae* attained 97.08%, but it was 91.69, 89.64, 81.57 and 65.48% for the same storage periods, respectively (Table 3).

Table 2 Effect of different selected emergence times of parasitoids, *Trichogramma evanescens* and *Trichogrammatoidea bactrae*, reared on the host insect, *Sitotroga cerealella* eggs > 24 h

Emergence times (hrs)	No. parasitoids	No. exposed eggs	No. parasitized eggs	% parasitism	No. emerged parasitoid adults	% of emergence	Developmental period (Days)
Trichogramma evanescens							
0	701.00	839.50	798.25 ± 22.42	95.06 a	710.75 ± 13.82	89.11 a	7.75 ± 0.25
4	633.00	554.25	506.75 ± 21.86	91.45 ab	447.75 ± 17.80	88.45 a	7.50 ± 0.29
8	544.33	635.00	571.50 ± 12.18	90.38 ab	472.50 ± 15.48	82.65 a	7.50 ± 0.29
16	660.00	761.75	671.00 ± 49.63	88.22 ab	538.25 ± 30.66	81.06 a	7.25 ± 0.25
32	580.00	832.25	715.75 ± 45.13	86.04 b	564.00 ± 36.21	79.09 ab	7.25 ± 0.25
64	508.67	348.75	254.50 ± 17.59	73.79 c	175.50 ± 4.21	70.00 b	8.50 ± 0.29
L.S.D.5%				8.1697		10.5676	
Trichogrammatoidea bactrae							
0	394.67	405.75	393.25 ± 12.87	96.90 a	362.00 ± 10.98	92.14 a	8.75 ± 0.25
4	588.00	594.50	560.50 ± 63.07	94.47 ab	508.25 ± 52.72	90.92 ab	8.75 ± 0.25
8	379.00	404.75	375.25 ± 29.62	93.23 abc	322.00 ± 27.01	86.30 ab	8.75 ± 0.25
16	581.67	600.75	547.50 ± 4.63	91.17 bcd	442.00 ± 16.71	80.74 bc	8.75 ± 0.25
32	437.67	438.25	393.25 ± 35.12	90.10 cd	310.00 ± 14.72	79.63 bc	8.50 ± 0.29
64	425.00	428.75	380.75 ± 15.42	88.81 d	275.25 ± 8.56	72.94 c	8.50 ± 0.29
L.S.D.5%				4.2342		11.2967	

% followed by the same letters do not differ significantly at P < 0.05 (L.S.D. test)

Table 3 Effect of using the cold-stored eggs of *Sitotroga cerealella* on the parasitoids, *Trichogramma evanescens* and *Trichogrammatoidea bactrae*

Cold-stored *S. cerealella* eggs (Days)	No. cold exposed eggs	No. parasitoids	No. parasitized eggs	% parasitism	No. emerged parasitoid adults	% of emergence	Developmental period (Days)
Trichogramma evanescens							
Control*	492.75	540.25	474.50 ± 11.53	96.41 a	445.50 ± 16.33	93.84 a	7.25 ± 0.25
5	584.50	668.50	511.25 ± 23.49	87.78 b	464.75 ± 14.69	91.16 ab	8.25 ± 0.25
10	358.50	604.25	315.25 ± 49.26	87.50 b	261.25 ± 28.16	84.58 ab	8.25 ± 0.25
20	373.75	338.00	297.50 ± 19.39	79.71 c	237.00 ± 33.77	78.47 bc	8.25 ± 0.25
40	467.50	589.00	285.00 ± 19.11	61.41 d	186.25 ± 7.09	66.00 c	8.25 ± 0.25
L.S.D.5%				7.3133		14.1832	
Trichogrammatoidea bactrae							
Control*	501.25	530.50	486.75 ± 14.96	97.08 a	472.50 ± 10.68	97.07 a	9.25 ± 0.25
5	545.33	438.00	499.75 ± 20.41	91.69 ab	469.50 ± 12.69	94.11 ab	9.25 ± 0.25
10	489.75	524.00	435.75 ± 22.05	89.64 ab	385.50 ± 6.85	89.03 ab	9.75 ± 0.25
20	262.75	322.75	295.25 ± 25.50	81.57 b	233.50 ± 17.82	80.09 bc	9.25 ± 0.25
40	351.00	332.25	225.25 ± 20.69	65.48 c	155.50 ± 12.52	71.16 c	9.25 ± 0.25
L.S.D.5%				15.3736		16.4045	

% followed by the same letters do not differ significantly at $P < 0.05$ (L.S.D. test)

Control* = non-stored *S. cerealella* eggs

Rate of parasitized eggs (RP)

Emergence percentage of each of the 2 tested parasitoids' adults varied significantly among the cold storage periods than those of non-stored host eggs (control). The emergence rate of *T. evanescens* adults ranged between (66.00–91.16%) in the cold storage durations of (5–40 days), respectively. Compared to the non-cold-stored eggs (97.07%), *T. bactrae* emergence rate decreased to 94.11, 89.03, 80.09 and 71.16% in cold-stored eggs 5, 10, 20 and 40 days, respectively (Table 3).

Developmental periods (DP)

Periods of *T. evanescens* development ranged between (7.25–8.25 days) for (0–40 days) host storage eggs, while for *T. bactrae*, those periods were 9.25, 9.25, 9.75, 9.25 and 9.25% for egg stored to 0, 5, 10, 20 and 40 days, respectively, at 27± 1°C (Table 3). Results indicated that the developmental periods of both parasitoid species had non-significant differences in tested cold-stored eggs (Table 3).

Statistically, each of the biological aspects, non-significant difference was obtained between the 2 parasitoids, *T. evanescens* and *T. bactrae*, for the three tested parameters (host egg-ages, parasitoids' emerging time, cold host storage) (Table 4).

Table 4 T test analysis of variance affecting the biological aspects between the two parasitoids

Variables	t-value	Level (Prob > t)	df	Significance (0.05)
Sitotroga cerealella old eggs				
% of parasitoids' parasitization	− 0.2564	0.8028	10	NS
% of parasitoids' emergence	− 0.3370	0.7431	10	NS
Parasitoids' emergence times				
% of parasitoids' parasitization	− 1.5259	0.1580	10	NS
% of parasitoids' emergence	− 0.4944	0.6317	10	NS
Cold-stored *S. cerealella* eggs				
% of parasitoids' parasitization	− 0.3133	0.7620	8	NS
% of parasitoids' emergence	− 0.5053	0.6270	8	NS

Effect of host egg-ages, parasitoids' emerging time, cold host storage on *T. evanescens* and *T. bactrae* emergence percentage of F1 progeny

Figure 1 shows that 0 h.-old eggs of the host *S. cerealella* were the most age caused emergence of F1 progeny for *T. evanescens* (80.65%) and *T. bactrae* (87.66%). The emergence rate was decreased gradually by increasing the host egg-ages (2, 4, 8, 16 and 32 h.). It was (78.26, 70.88, 66.12, 54.49 and 41.97%) for *T. evanescens* and (81.41, 71.76, 68.58, 59.51 and 48.33%) for *T. bactrae*, at the same host egg-ages, respectively. There were significant differences among the emergence rate resulted from different host egg-ages ($F = 8.91347$, $P > 0.0002$, $df = 5$, $LSD5\% = 14.8376$) for *T. evanescens*

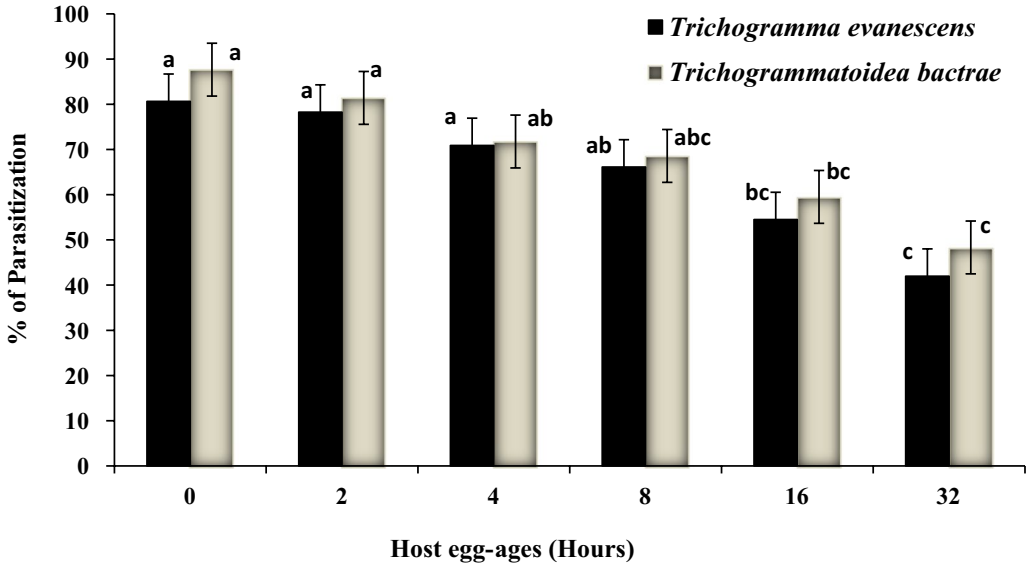

Fig. 1 F1 emergence rate of *Trichogramma evanescens* and *Trichogrammatoidea bactrae* reared on different egg-ages of *Sitotroga cerealella*

and (F = 4.3405, $P > 0.0091$, df = 5, LSD5% = 20.4244) for *T. bactrae*.

Percentage of F1 progeny emerging was an indicator for the suitable emerged parasitoids' time. Rates differed according to the tested emerged parasitoids' times (0, 4, 8, 16, 32 and 64 h.) for *T. evanescens* (91.10, 90.79, 80.97, 72.36, 72.36, 49.50 and 18.29%, respectively) and *T. bactrae* (93.04, 85.29, 86.35, 77.77, 54.98 and 21.58%, respectively). Results observed that the shortest emergence time was more suitable for rearing both parasitoids' species (Fig. 2). Emergence rate differed significantly for *T. evanescens* (F = 39.7754, $P > 0.0001$, df = 5, LSD5% = 13.9057) or *T. bactrae* (F = 27.0475, $P > 0.0001$, df = 5, LSD5% = 16.0351) between the tested emerged times.

Figure 3 shows the emergence rate of *T. bactrae* in F1 progeny. It was more than *T. evanescens* along the cold storage durations at 8°C. Comparing to the non-stored *S. cerealella* eggs, the emergence rate of F1 progeny declined (89.67, 81.42, 75.19, 62.01 and 45.06%) for *T. evanescens* and (91.71, 88.80, 79.43, 67.13 and 51.83%) *T. bactrae* as the cold-stored host eggs increased (0, 5, 10,

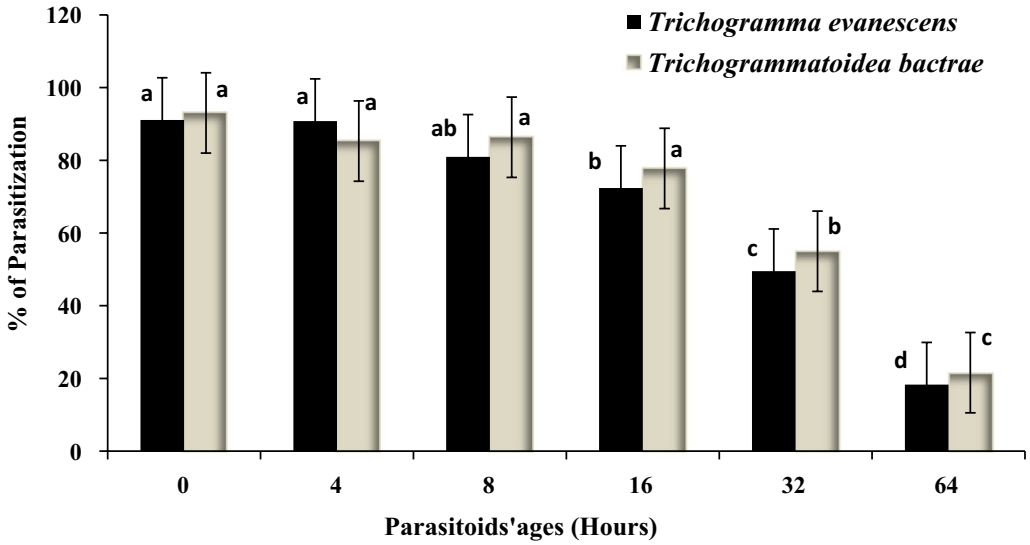

Fig. 2 F1 emergence rate of *Trichogramma evanescens* and *Trichogrammatoidea bactrae* resulted from tested parasitoid time emergences

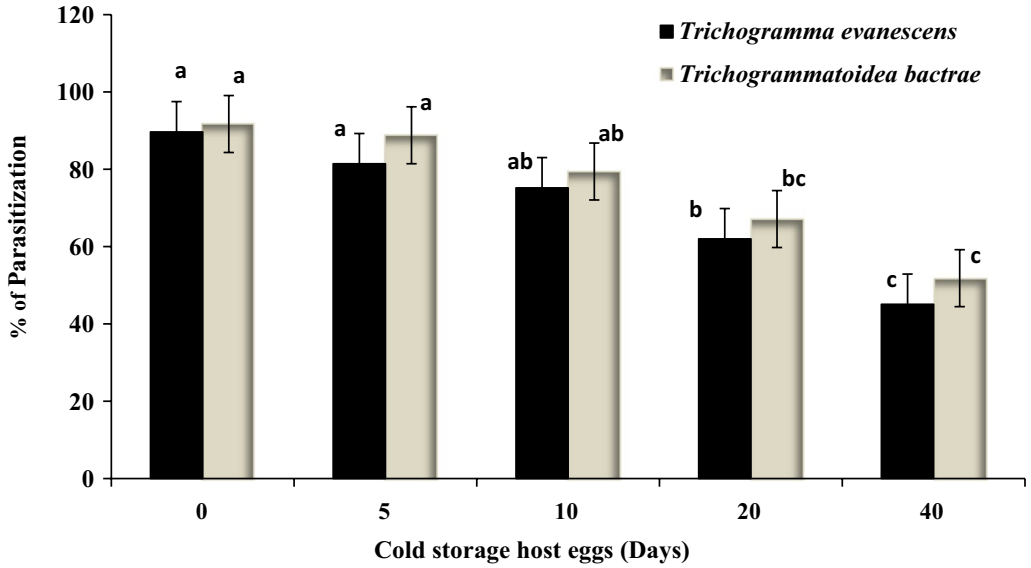

Fig. 3 F1 emergence rate of *Trichogramma evanescens* and *Trichogrammatoidea bactrae* resulted from *Sitotroga cerealella* cold-stored eggs

20 and 40 days), respectively. F1 emergence rate had significant differences at cold host-stored *S. cerealella* eggs (F = 12.3237, $P > 0.0001$, df = 4, LSD5% = 15.0423) and (F = 10.50375, $P > 0.0003$, df = 4, LSD5% = 15.3141) of *T. evanescens* and *T. bactrae*, respectively.

Discussion

The host age is one of the most important factors affected parasitism and parasitoid's efficiency to parasitize. *Trichogramma* spp. parasitized and emerged from all *S. cerealella* egg-ages, but they were decreased significantly when the oldest host eggs were utilized. Developmental time of parasitoids was non-significantly varied between hot egg-ages, but longer in older eggs than in younger ones. This finding was in agreement with Atashi et al. (2021) when *Trichogramma euproctidis* (Girault) developed faster in small old eggs rather than the old ones. Also, the youngest host eggs were used than the oldest ones to ensure the persistence of parasitoid mass production. Godin and Boivin (2000) mentioned that *Trichogramma* spp. were unable to complete their development in the oldest eggs. The number of parasitized eggs (9.60 eggs) was the highest for host aged 24 h followed by those of 48 h (1.00 egg), while no parasitism occurred for 72 h host egg-age (de Queiroz et al. 2020). At 25°C, *T. euproctidis* parasitized one-day-old eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) were developed through 8.9 days (Hansen and Jensen 2002) and 9.8 days (Tabebordbar et al. 2020). El-Mandarawy and Rizk (2002) found that parasitization percentage between the two studded parasitoids was significantly differed. Additionally, a disagreement with the present study was recorded where parasitization and fecundity were higher in *T. evanescens* than *T. bactrae* reared from two stored pests, *Callosobruchus maculatus* (Fabricius) (Coleoptera: Chrysomelidae) and *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae).

Parasitism and emergence rate was gradually decreased as the emergence time of the two tested parasitoid species increased. The rate of *S. cerealella* parasitized eggs decreased significantly with increasing parasitoids' age. The rate of parasitism reached its peak in control and decline at the parasitoid ages of 8 and 16 h, and then, it began to decrease until reached the lowest rate at the age of 64 h. These results agree with Taha et al. (2022) who recorded a significant decrease in *T. evanescens* emergence percentages among parasitoid emerging times. Shawer et al. (2021) found that the emergence rate of *T. evanescens* was generally hosted egg-ages-dependent.

Parasitism rate was high in non-stored host eggs (control) compared to the cold host-stored eggs at different tested periods. Cold-stored eggs were affected significantly by the parasitism and emergence rate of *Trichogramma* spp. Results were in agreement with Rodrigues and Sampaio (2011) who observed that cold storage period at 8–10 °C had nonnegative effect. Lessard and Boivin (2013) observed negative effects on F1 progeny, where the period of cold storage host eggs increased the F1 emergence rate decreased. Age-dependent storage egg kept at either 4 or 9 °C was significantly influenced the parasitism percentages of *Plodia interpunctella* (Hübner) eggs by *T. evanescens* (Haque et al. 2021).

Percentage of F1 progeny emerging was an indicator for the suitable emerged parasitoids' time. Aging of host eggs

at the parasitism appears to affect emergence of progeny F1 where negative relationship between emerging time and the emerging percentages of F1 was recorded (Shawer et al. 2021). Emergence of progeny F1 of both the two parasitoids varied significantly according to the emergence time (Taha et al. 2022).

Conclusion

It was concluded that the egg-ages of *S. cerealella* influenced the parasitization and emergence rate of two *Trichogramma* parasitoid spp. The least parasitoid emergence time was more suitable for rearing both of the two parasitoid spp., *T. evanescens* and *T. bactrae*. Data revealed that *S. cerealella* eggs cold stored at 5 and 10 days at 8°C are more suitable for the rate productivity of *Trichogramma* spp. Developmental time of parasitoids was longer in older eggs than in younger ones. Under laboratory conditions, *T. bactrae* was less affected by the tested parameters than *T. evanescens.*

Abbreviations

RP Rate of parasitized eggs
RE Rate of emerged adults
DP Developmental periods of parasitoid adults

Author contributions

Esraa M. Abdel Halim was involved in writing, El-Mandarawy M. R contributed to methodology, formal analysis, investigation and writing, Ahmed S.S. was involved in visualization and reviewing, and Magda contributed to visualization. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Biological Control, Plant Protection Research Institute, Agriculture Research Center, Giza, Egypt. [2]Department of Economic Entomology and Pesticides, Faculty of Agriculture, Cairo University, Giza, Egypt.

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