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Role of host diet on the fitness of the egg parasitoid species, *Trichogramma evanescens* Westwood (Hymenoptera: Trichogrammatidae)

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Abstract

Background: Egg parasitoids belonging to the genus *Trichogramma* (Hymenoptera: Trichogrammatidae) are important natural enemies that have been successfully used in biological control programs and mostly reared on the Mediterranean flour moth, *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae). Host quality is a crucial factor that can determine parasitoid fitness.

Main body: Laboratory studies were carried out to evaluate the effects of 3 different larval diets CY diet (95% cornmeal + 5% yeast), CBGY diet (53.3% cornmeal + 26.7% wheat bran + 15% glycerine + 5% yeast), and WBGY diet (53.3% wheat flour + 26.7% wheat bran + 15% glycerine + 5% yeast) on some demographic parameters of *E. kuehniella*. Moreover, the performance of the species *Trichogramma evanescens* Westwood reared on the *E. kuehniella* eggs reared on the 3 artificial diets were determined. For the *E. kuehniella* rearing, the CY diet had a higher fecundity and greater emergence ratios. Nevertheless, CY diet also provided shorter developmental time, greater fecundity, and relatively higher female ratios of subsequent generations of the parasitoids.

Conclusion: The results suggest that the CY diet could be considered as a standard diet for the multigenerational rearing of *T. evanescens*.

Keywords: *Ephestia kuehniella*, *Trichogramma evanescens*, Host quality, Mass-rearing, Parasitoid fitness

Background

Hymenopteran parasitoids are a key group of beneficial organisms that are used in augmentative biological control programs because they are more specific than predators and have a much more restricted host range, which is considered important in preventing undesirable side effects (Bigler et al. 2006; van Lenteren 2012). Egg parasitoids of the genus *Trichogramma* are important biological control agents that have been successfully used against a wide range of lepidopteran pests for more than 100 years via conservation strategies, artificial releases alone (El-Arnaouty et al. 2014; Wang et al. 2014) or in combination with insecticide applications (Parsaeyan et al. 2020). *Ephestia kuehniella* Zeller, *Corcyra cephalonica* (Strainton), *Galleria mellonella* (Linnaeus) (Lepidoptera: Pyralidae), *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), and *Antheraea pernyi* (Guérin-Méneville) (Lepidoptera: Saturniidae) are the most commonly used factitious hosts worldwide for the rearing of *Trichogramma* parasitoids (Abd El-Hafez 2001; El-Wakeil 2007; Wang et al. 2014).

Mass production of natural enemies is the base of augmentative biological control that is often a commercial activity because of the need for large scale regular releases of beneficial insects (van Lenteren 2012). Mass-produced natural enemies must compete with other pest control technologies to become commercially viable and

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sustainable. Producers of commercial natural enemies throughout the world have developed a variety of simple and highly productive rearing systems for *Trichogramma* spp. (Morales-Ramos et al. 2014). However, the costs of the host production are one of the most important parameters that can directly impact mass-rearing investments. Generally, factitious hosts are used to reduce the cost or to increase the efficiency of the mass-reared parasitoids (El-Wakeil 2007). *E. kuehniella* can be reared on basic and inexpensive diets, such as wheat/corn flour and many other cereal products (Locatelli et al. 2008). There have been several attempts to reduce the host costs with basic or complex diets (Farahani et al. 2016; Moghaddassi et al. 2019).

However, the economic optimization of the host mass rearing is not the unique factor that should be considered when defining a parasitoid commercial rearing. Indeed, the performance of parasitoids reared on cheaper hosts should be also taken into account for successful and sustainable mass-rearing and pest control performances (Ali and Wright 2020). For the egg parasitoids that all their immature stages develop inside the host, the host represents the sole source of nutrients (Farahani et al. 2016). The characteristics of host egg quality such as nutritional content, egg volume, chorion thickness, and size directly affect the parasitoid wasp fitness (Abd El-Hafez 2001; El-Wakeil 2007). Determining the role of host diet on the development and other biological parameters of *Trichogramma* spp. could improve the success of biological control programs.

Consequently, the aim of this study was to determine firstly: (i) the effects of different diets on some biological parameters of the factitious host, *E. kuehniella*, and (ii) biological traits of *T. evanescens* on the eggs of *E. kuehniella* fed on three different diets.

Materials and methods

Rearing of insects

Ephestia kuehniella

The initial colony of *E. kuehniella* was derived from the Biological Control Research Institute, Adana, Turkey. The moths have been maintained in the laboratory for 3 years before being used in the experiments. Its larvae were reared on a wheat flour: wheat bran (2:1) mixture, in a climate chamber at 25 °C, 60% RH under a 14:10 h (L: D) photoperiod.

Trichogramma evanescens

A colony of *T. evanescens* was established from parasitized egg-masses collected from maize fields. The parasitoid species was identified by Dr. Viktor Fursov, the Department of Entomophagous Insects and Biocontrol, Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine, Kyiv, Ukraine. The parasitoid wasps were reared on 1-day-old *E. kuehniella* eggs that were previously sterilized by ultraviolet irradiation, in climate chambers at 25 °C, 70% RH under a 14:10 h (L:D) photoperiod. The 0–24-h-old sterilized eggs of *E. kuehniella* were glued on paper strips (1 × 8 cm) with 10% Arabic gum. The strips were placed in glass tubes (2.5 × 16 cm) and exposed to the adults of *T. evanescens* with 50% honey-water solution that was provided in film form as nutrient source. To maintain the colony, parasitized eggs of *E. kuehniella* were transferred into new glass tubes after 8 days and kept at the same conditions until emergence of the parasitoids.

Effect of different diets on the development of *Ephestia kuehniella*

Three different larval diets, CY diet (95% cornmeal + 5% yeast), CBGY diet (53.3% cornmeal + 26.7% wheat bran + 15% glycerine + 5% yeast), and WBGY diet (53.3% wheat flour + 26.7% wheat bran + 15% glycerine + 5% yeast), were provided to *E. kuehniella* larvae. All diets used in the experiments were the same with Kurtuluş et al. (2020) which provided the most promising results in terms of rearing of *E. kuehniella* under laboratory conditions. However, preliminary studies showed that the size of the rearing boxes can affect the fecundity and development of the moths. Therefore, the experiments were carried out in big boxes (30 × 15 × 10 cm) to unravel the efficiency of mass rearing method.

Dry matter, ash, lipid, and crude protein content of each diet are indicated in Table 1. Nitrogen percentage in the diet was calculated using Micro-Kjeldahl (AOCS 1989). The protein percentage was measured by multiplying the nitrogen percentage with a constant 6.25. Oil was extracted from the diets using Soxhlet, and the oil percentage was estimated according to the Association of Official Analytical Chemists (AOCS 1989).

One kilogram from each diet was used at all experiments. Pre-weighed diet mixtures were respectively placed in the plastic boxes (30 × 15 × 10 cm), and 3000 *E. kuehniella* eggs were homogeneously dispersed in each container. To determine the 3000 eggs, firstly 100 eggs were counted under a stereoscopic microscope (× 45 magnifications) (Olympus SZ51) and weighed on a precision scale (0.0001 g) (Dikomsan, FGH 200). After the calculation of the weight of the 100 eggs, it was multiplied by 30 to ensure sufficient amounts of 3000 eggs' weight. Plastic boxes were kept in the climate

Table 1 Contents of *Ephestia kuehniella* diets tested (%)

	Dry matter	Ash	Lipid	Crude protein
CY	90.29 ± 0.11	0.95 ± 0.04	1.43 ± 0.08	6.34 ± 0.04
CBGY	90.77 ± 0.22	1.56 ± 0.08	1.08 ± 0.02	5.86 ± 0.05
WBGY	90.12 ± 0.24	1.25 ± 0.09	1.34 ± 0.02	6.41 ± 0.02

Diet names were constructed with the initials of the ingredients of each diet *C* cornmeal, *W* wheat flour, *B* wheat bran, *G* glycerine, *Y* yeast

Table 2 Biological traits of *Ephestia kuehniella* when fed on three diets

Diets	Preimaginal development time (days)	Pupal weight (mg) (mean ± SE)		Adult emergence (%)
		Female	Male	
CY	44.20 ± 0.37a	22.79 ± 0.27b	18.70 ± 0.19b	84.63 ± 5.43a
CBGY	42.40 ± 0.25b	23.37 ± 0.26b	20.54 ± 0.16a	86.99 ± 3.86a
WBGY	42.60 ± 0.25b	24.88 ± 0.22a	20.73 ± 0.20a	85.66 ± 3.06a

Means (± SE) with same letter in the same column are not statistically significant according to Tukey's HSD test ($p < 0.05$)

chamber at 25 °C, 60% RH under 14:10 (L: D) h photoperiod. Larvae were checked daily up to pupal stage. Following the emergence of the pupae, 100 pupae (four corners and one center from the plastic boxes) were removed for each replicates with the help of soft tweezers and separated as males and females under a stereoscopic microscope at × 45, based on their external genitalia. The separated pupae were weighed individually on a precision scale (0.0001 g). Weighed pupae were transferred into plastic containers (5 × 3 × 3 cm) and placed in the same climate chamber. To determine the adult emergence, hatched pupae numbers were checked, and preimaginal development time were recorded. Experiments were carried out in a completely randomized design with 5 replicates for each diet.

Effects of different diets on the reproduction of *Ephestia kuehniella*

All individuals obtained from the same diet were transferred by an electronic collector into the plastic oviposition cages (30 × 20 cm, all sides windowed and covered with fine muslin to provide ventilation and oviposition site for the adult moths). For each diet, all replicates were kept in different oviposition cages and placed in a rearing room at the aforementioned conditions. Oviposition cages were checked daily, and all eggs were collected with the help of the brush and put inside the airtight plastic containers (20 cc). The collected eggs were weighed on a precision scale daily (0.0001 g). A hundred eggs were counted from the plastic containers randomly and weighted. Total weight of the eggs collected daily was divided to weight of 100 eggs. Following the determining of the daily egg number, total fecundity of *E. kuehniella* was detected. For the maximum benefit of the oviposition, cages were kept 4 days with the adult moths, and then, the cages were discarded.

Effects of different *Ephestia kuehniella* diets on the development, reproduction, and longevity of *Trichogramma evanescens*' F_0 and F_1 generations

Newly emerged wasp adults obtained from the laboratory colony (F_0) were left inside the glass tubes (2 × 10 cm) at least 12 h for copulation, and then, one female individual was transferred into a new tube. Fifty 24-h-old sterilized *E. kuehniella* eggs were glued on paper strips (1 × 4 cm) with 10% Arabic gum and provided to *T. evanescens* for 24 h. After the exposure process, the paper strips were renewed, and the older one was transferred to separated glass tube for observation of wasp's development. Once the parasitized eggs were blackened (after 4 days), they were counted under a stereomicroscope, and following the adult emergence rate, the female and male ratio of the parasitoid was determined. Emergence rates were recorded by counting emergence holes from black eggs. Since *T. evanescens* can lay most of their eggs in 2 days (Achiri et al. 2020), the experiments were

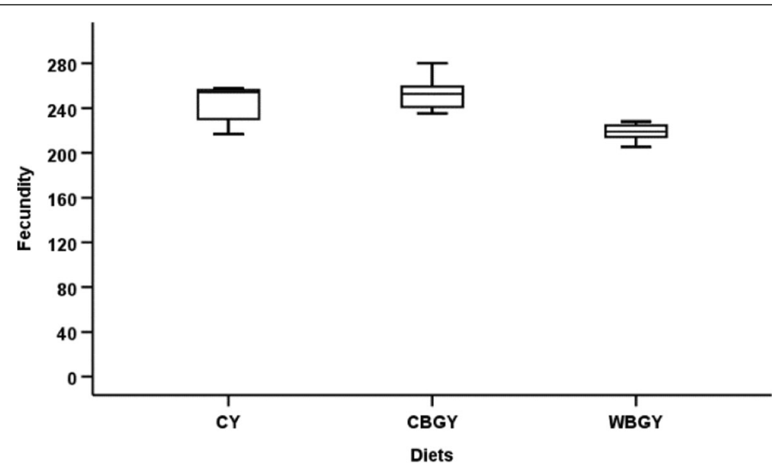

Fig. 1 Number of the eggs laid by *Ephestia kuehniella* feeding on three diets

Table 3 Generalized linear model (GLM) analysis for the development of *Trichogramma evanescens* on host eggs reared from different diets

Source	df	Mean square	F	*p* value
Fixed factors				
Diets	2	.755	4.236	**.016**
Generations	1	.135	.756	.386
Parasitization days	1	.259	1.454	.230
Combine effects				
Diets*generations	2	1.026	5.760	**.004**
Diets*parasitization days	2	.136	.761	.469
Generations*parasitization days	1	.050	.281	.597
Diets*generations*parasitization days	2	.023	.131	.878
Error	138	.178		

concluded after 48 h. To determine longevity, all alive individuals were kept unfed in the same tubes and checked 2 times a day to count dead individuals. For F1 generation experiments, following the adult emergences from the F_0 experiments, different host eggs were provided to parasitoid wasp at the aforementioned conditions. The experiments were carried out for both generations in a completely randomized design, at least 10 replicates for each diet, in climate chambers at 25 °C, 70% RH under a 14:10 (L:D) h photoperiod.

Statistical analysis

The experiments were carried out in a completely randomized design. Generalized linear model (GLM) analysis was used to determine the effects of diets, generations, and parasitization days on the development and fecundity of *T. evanescens*. In the GLM, developmental time and fecundity of *T. evanescens* were modeled as dependable variables, with host diets, generations, and parasitization days as fixed factors. Kolmogorov-Smirnov test and Levene's test were used to determine normality and homogeneity of variance, respectively. One-way analysis of variance (ANOVA) was conducted on development time and fecundity of *E. kuehniella* and *T. evanescens*, followed by Turkey's post hoc mean separation. Pupation ratios and emergence rates were arcsine transformed before carrying out one-way ANOVA and Tukey's post hoc mean separation. Data of pupal weight (male and female) were also analyzed with one-way ANOVA, followed by Turkey's post hoc. All analyses were done using SPSS© (ver. 25).

Table 4 Total development time and longevity of *Trichogramma evanescens* on different host diet eggs

Diets	Total development time (days)		Longevity (days)	
	F_0	F_1	F_0	F_1
CY	8.49 ± 0.09a	8.42 ± 0.08a	2.81 ± 0.33a	2.77 ± 0.20a
CBGY	8.45 ± 0.12a	8.32 ± 0.08a	3.02 ± 0.14a	2.86 ± 0.15a
WBGY	8.43 ± 0.10a	8.82 ± 0.07b	2.95 ± 0.09a	2.64 ± 0.23a

Means (± SE) with same letter in the same column are not statistically significant according to Tukey's HSD test ($p < 0.05$)

Results and discussion

Effects of different diets on the development of *Ephestia kuehniella*

The nutrient contents of the larval diet affect the developmental time of lepidopteran insects (Moghaddassi et al. 2019). In this study, the preimaginal developmental time was significantly shorter when larvae were fed on more complex diets, CBGY and WBGY, than the basic diet, CY ($F_{2,12}$ = 11.231, p = 0.002; Table 2). Kurtuluş et al. (2020) found positive effects of the additional ingredients as shortest developmental time was obtained from most complex diets: CBGY and WBGY. This was attributed to additional ingredients that reduced the developmental time of moths. Many studies agreed with these results that the basic diets containing generally wheat or cornmeal showed longer developmental time (Locatelli et al. 2008; Kurtuluş et al. 2020), than the complex diets containing rich protein, carbohydrate, and lipid content (Moghaddassi et al. 2019; Kurtuluş et al. 2020). Not only the different larval diets can affect the developmental time but also pupal weight and emerging ratios as well. According to results obtained from this study, the mass of female and male *E. kuehniella* pupae from the larvae reared on the diet WBGY was significantly greater than the mass of pupae from the other diets for both sexes (females: $F_{2,623}$ = 20.042, p < 0.0001; males: $F_{2,871}$ = 36.407, p < 0.0001). Kurtuluş et al. (2020) noted that composite larval diets had a great impact on pupal weights of *E. kuehniella*, and the average female pupal weights were always higher than those of males from the same type of diet. All results were similar with this study, but the pupal weight was relatively higher than in this study. This could be related to the size of the boxes or the number of the replicates in which 500 pupae were evaluated in this study. In general, higher

Table 5 Generalized linear model (GLM) analysis for parasitization parameters of *Trichogramma evanescens* on host eggs reared on different diets

Source	df	Mean square	F	*p* value
Fixed factors				
Diets	2	174.156	2.319	.102
Generations	1	29.607	.394	.531
Parasitization days	1	3930.070	52.339	**.000**
Combine effects				
Diets*generations	2	110.879	1.477	.232
Diets*parasitization days	2	74.153	.988	.375
Generations*parasitization days	1	339.335	4.519	**.035**
Diets*generations*parasitization days	2	43.459	.579	.562
Error	138	75.089		

pupal weight is a light of evidence that can increase the fecundity of moths (Heisswolf et al. 2009). Previous studies remarked that higher pupal weight can be correlated to the lifetime fecundity (Kurtuluş et al. 2020). However, it should be also taken into consideration that the moths arising from pupae of similar weights from different larval diets showed significant differences in fecundity (Moghaddassi et al. 2019). Thus, pupal weight is not a factor that can only be explained with higher fecundity. Moreover, the number of offspring that directly reach the adult stage is also a crucial factor for the total fecundity of insects. The emergence ratios of *E. kuehniella* adults from either the basic or complex diets were similar in this study ($F_{2,12}$ = 0.649, p = 0.540; Table 2). Many studies agreed that there were non-significant differences between emergence ratios of *E. kuehniella* even if the moths were reared on different larval diets (Kurtuluş et al. 2020).

Effects of different diets on the reproduction of *Ephestia kuehniella*

Availability of adequate nutrition is of crucial importance for successful reproduction. Many studies reported effects of diet quality and quantity on female reproduction in insects and thereby on fitness (Kurtuluş et al. 2020). In this study, the average number of eggs collected from CY and CBGY diets was significantly higher than from the WBGY diet ($F_{2,12}$ = 6.854, p = 0.010; Fig. 1). It showed that cornmeal and yeast had a greater effect on the fecundity of the moths.

Lima-Filho et al. (2001) obtained less egg from the diet containing cornmeal + yeast (97.0% + 3.0%). However, this outcome could be related to the difference between the yeast ratios and larval density. Kurtuluş et al. (2020) reported that an increase in fecundity was observed with complexity of diet, while percent fertility tended to reduce. With this study, the total fecundity of all diets was lower than reported by Kurtuluş et al. (2020). For the maximum benefit of the oviposition, the cages were kept for 4 days in this study, but they counted lifetime fecundity. Moreover, there are many studies that used yeast and glycerine as an additional ingredient to increase fecundity and yielded a little higher egg numbers (Moghaddassi et al. 2019). The environmental conditions, the origin of the ingredients, and larval density could be the reasons for these differences. On the other hand, the diets that contain glycerine or honey may cause fungal infections, if kept longer than the standard generation period. In the present study, CY diet had the potential for mass-rearing of natural enemies because of its higher fecundity and easy preparation. Kurtuluş et al. (2020) suggested that the same diet could be considered as a standard diet for the rearing of parasitoids and predators.

Effect of different *Ephestia kuehniella* diets on the developmental time and longevity of *Trichogramma evanescens*

Host quality is a critical factor that can determine the developmental rate and success of parasitoids (Liu et al. 2013). For the egg parasitoids that develop inside the

Table 6 *Trichogramma evanescens* parasitizing eggs of *Ephestia kuehniella* fed on three different diets

Diets	*n*	Parasitization per F_0 female		*n*	Parasitization per F_1 female		Total parasitization per female	
		1st day	2nd day		1st day	2nd day	F_0	F_1
CY	17	23.88 ± 2.08a	14.94 ± 2.47a	9	26.33 ± 3.63a	19.89 ± 1.73a	38.82 ± 3.94a	46.22 ± 4.07a
CBGY	12	25.83 ± 3.47a	10.33 ± 2.88a	12	24.25 ± 1.53a	14.58 ± 2.22a	36.17 ± 5.35a	38.83 ± 2.95ab
WBGY	14	26.71 ± 2.59a	10.64 ± 2.00a	11	19.36 ± 2.07a	13.36 ± 1.57a	37.36 ± 3.79a	32.73 ± 3.01b

Means (± SE) with same letter in the same column are not statistically significant according to Tukey's HSD test (p < 0.05)

Table 7 Hatching ratios of *Trichogramma evanescens* parasitizing eggs of *Ephestia kuehniella* fed on three different diets

Diets	*n*	Hatching ratios of parasitized eggs from F_0 (%)		*n*	Hatching ratios of parasitized eggs from F_1 (%)		Total hatching ratios of parasitized eggs (%)	
		1st day	2nd day		1st day	2nd day	F_0	F_1
CY	17	90.64 ± 1.19a	86.30 ± 3.14a	9	89.01 ± 2.52a	81.92 ± 2.96a	88.47 ± 1.82a	85.46 ± 1.74a
CBGY	12	91.14 ± 2.03a	84.29 ± 5.75a	12	84.75 ± 2.43a	79.51 ± 4.02a	87.68 ± 3.08a	82.13 ± 2.34a
WBGY	14	89.74 ± 2.56a	81.84 ± 4.58a	11	88.83 ± 3.36a	82.36 ± 3.47a	85.79 ± 2.48a	85.09 ± 2.61a

Means (± SE) with same letter in the same column are not statistically significant according to Tukey's HSD test ($p < 0.05$)

same host, the host represents the sole source of nutrients. Several species of factitious hosts are used worldwide for rearing *Trichogramma* parasitoids including: *E. kuehniella*, *S. cerealella*, *C. cephalonica*, and *G. mellonella* (Linnaeus) (Shalaby et al. 2000; Abd El-Hafez et al. 2001; Hoffmann et al. 2001). In this study, the host diets (CY, CBGY, WBGY) and combined effects of diets and generations significantly affected the developmental time of *T. evanescens* (diets: $F_{2,138}$ = 4.236, p = 0.016; diets*-generations: $F_{2,138}$ = 7.760, p = 0.004, Table 3).

Many studies showed that *E. kuehniella* is an important factitious host for the rearing of *Trichogramma* parasitoids (El-Wakeil 2007; Özder and Kara 2010; Farahani et al. 2016; Moghaddassi et al. 2019). In the present study, the host diets did not affect the total developmental time of *T. evanescens*' F_0 generation; however, they were significantly different for F_1 generation (F_0: $F_{2,40}$ = 0.103, p = 0.903; F_1: $F_{2,29}$ = 12.490, p < 0.0001; Table 4). Total developmental time was significantly longer when the parasitoids were reared on the eggs from 2 generations on WBGY diet, but the longevity did not affect from the host diets of both generations (F_0: $F_{2,40}$ = 0.117, p = 0.927; F_1: $F_{2,29}$ = 0.345, p = 0.711; Table 4).

Effect of different *Ephestia kuehniella* diets on the reproduction of *Trichogramma evanescens*

Quality and quantity of food source are an important factor that can affect parasitoids' reproductive traits (El-Wakeil 2007; Moghaddassi et al. 2019). In the present study, the parasitization parameters of *T. evanescens* were not influence by different host diets ($F_{2,138}$ = 2.319, p = 0.102). However, the parasitization days and combined effects of generations*parasitization days significantly affected the fecundity of *T. evanescens* (parasitization days: $F_{1,138}$ = 52.339, p < 0001; generations*parasitization days: $F_{1,138}$ = 4.519, p = 0.035, Table 5).

For both generations, the parasitoid laid more eggs when the host eggs were provided within the first 24 h (Table 6). These results are in accordance with other studies showing that *T. evanescens* laid more eggs in the first 24 h (Achiri et al. 2020). It is known that the mean number of eggs laid per female generally decreases over time or with the age of the parasitoid (Reznik et al. 2009). *Trichogramma chilonis* Ishii on eggs of *C. cephalonica* and *T. cacoeciae* on *Cydia pomonella* (Linnaeus, 1758) (Lepidoptera: Tortricidae) eggs showed a systematic decrease in the numbers of eggs laid per female over time (Mansour 2019). Moreover, in this study, there were non-significant differences among the parasitization parameters of both generations in the same day ($F_{1,80}$ = 0.105, p = 0.905; Table 6). Yet, the parasitoids laid more eggs when exposed to eggs from CY diets for subsequent generations ($F_{2,29}$ = 3.912, p = 0.031; Table 6). Nathan et al. (2006) reported no differences in parasitization rate of *T. chilonis* when provided with *C. cephalonica* eggs from adults reared on different larval diets. However, Moghaddassi et al. (2019) showed that *T. brassicae* laid more eggs per female in the largest eggs that were obtained from *E. kuehniella* rich diet for the subsequent generations. These differences could be related to the nutritional content and size of the eggs.

Emergence of the parasitoids from different parasitized host eggs during the first 24 h was greater than on the second day hatching ratios for both generations. However, for the same days, the host diets did not affect the emergence of the *T. evanescens* adults (F_0: 1st day: $F_{2,40}$ = 0.128, p = 0.881; 2nd day, $F_{2,29}$ = 0.281, p = 0.756; F_1: 1st day: $F_{2,29}$ = 0.995, p = 0.382; 2nd day, $F_{2,29}$ = 0.187, p = 0.831; Table 7).

Table 8 Female ratios of *Trichogramma evanescens* parasitizing eggs of *Ephestia kuehniella* fed on three different diets

Diets	F_0 female ratios (%)		F_1 female ratios (%)		Total female ratios (%)	
	1st day	2nd day	1st day	2nd day	F_0	F_1
CY	88.33 ± 1.76a	81.12 ± 3.39a	93.17 ± 1.74a	77.03 ± 3.55a	86.13 ± 1.34a	86.71 ± 1.21a
CBGY	80.18 ± 6.03a	75.42 ± 8.30a	82.46 ± 2.34b	82.83 ± 2.98a	81.04 ± 5.41a	82.90 ± 1.70a
WBGY	89.68 ± 2.14a	87.43 ± 3.62a	87.17 ± 0.95ab	73.36 ± 3.36a	88.75 ± 1.98a	81.89 ± 1.50a

Means (± SE) with same letter in the same column are not statistically significant according to Tukey's HSD test ($p < 0.05$)

In general, emergence rates of parasitoids were similar at the same generations. In this study, the emergence rate of parasitoids was about 85% of the parasitized eggs by all larval diets. A similar pattern of results was obtained from others (El-Wakeil 2007; Farahani et al. 2016; Moghaddassi et al. 2019; Wang et al. 2019). Nutritional quality of host impacts adult parasitoid's fitness by increasing fecundity, host size, and offspring sex ratios (Farahani et al. 2016). For F_0 generations, the female ratios were similar for 2 days, but the host diets significantly affected the female ratios of the F_1 generations at the first day ($F_{2,29}$ = 8.205; p = 0.002). In total, there were non-significant differences among the host diets on the female ratios in the same generations (F_0: $F_{2,40}$ = 1.557, p = 0.223; F_1: $F_{2,29}$ = 2.464, p = 0.103; Table 8). But when CY diet eggs were provided to the parasitoids, female ratios were relatively higher than the others, especially for the second generation. This could be an important finding for understanding the suitability of host for the mass-rearing of the subsequent generations of parasitoids. The number of produced females is a crucial factor in explaining the success of mass-rearing programs (El-Wakeil 2007).

Conclusion

Understanding the impact of host diet on host acceptance by *Trichogramma* spp. could improve the success of biological control programs by ensuring high efficiency of the parasitoid performance in an inundative release. In the light of overall results, CY diet provided easy preparation, shorter developmental time, higher fecundity, and relatively higher female ratios of subsequent generations of the parasitoid. For further research, the efficacy of the parasitoids and predators that are reared on the CY diet could be determined against their target hosts in the field.

Abbreviations

ANOVA: One-way analysis of variance; GLM: Generalized linear model; L: Light; D: Dark

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Author's contributions

The author conceived, designed, and conducted the research. Moreover author analyzed data and typed the manuscript. The author(s) read and approved the final manuscript.

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The author declares that he has no competing interests.

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