EGYPTIAN ACADEMIC JOURNAL OF
BIOLOGICAL SCIENCES
ENTOMOLOGY
A

ISSN
1687-8809

WWW.EAJBS.EG.NET

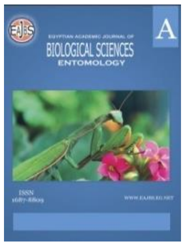
Vol. 17 No. 3 (2024)

Citation: *Egypt. Acad. J. Biolog. Sci. (A. Entomology) Vol. 17(3) pp.25-37 (2024)*
DOI: 10.21608/EAJBSA.2024.373305

Egypt. Acad. J. Biolog. Sci., 17(3):25-37 (2024)

Egyptian Academic Journal of Biological Sciences
A. Entomology

ISSN 1687- 8809
http://eajbsa.journals.ekb.eg/



Effect of Rearing *Galleria mellonella* and *Plodia interpunctella* Naturally and Artificially on Their Biological Aspects and The Morpho-Biological Features of *Trichogramma turkestanica*

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ARTICLE INFO
Article History
Received:8/7/2024
Accepted:12/8/2024
Available:16/8/2024

Keywords:
Galleria mellonella, *Plodia interpunctella*, artificial diets, *Trichogramma turkestanica*.

ABSTRACT

The present study was initiated to validate whether the artificial or natural diets are the best for *Galleria mellonella* and *Plodia interpunctella* hosts for rearing *Trichogramma turkestanica* Meyer and to assess the effect of reared host eggs on the morpho-biological features of *Trichogramma turkesta, nica* and their suitability for parasitism.

Results for the life tables parameters indicate that the shortest generation time and the lowest doubling time (DT) were recorded *Plodia interpunctella* which reared artificially (*Plodia* A), while the highest net reproductive rate (R_0) was recorded for *Galleria mellonella* which reared artificially (*Galleria* A). The artificial diets are better than those for the natural diet for rearing *G. mellonella* and *P. interpunctella* and their generation periods in terms of the measured parameters.

Results concerning the morphological features of *Trichogramma* females that were reared on the eggs of *Galleria* fed on artificial and natural diets were hosts better than *Plodia* A., *Sitotroga* N., and *Plodia* N under laboratory conditions. Also, the obtained data prove that the maximum mean percentage of successful parasitism and the maximum number of emerged female parasitoids were for *Galleria* A. In comparison, the rate of emerged adults from parasitized eggs was for *Plodia* A. It is of interest to point herein that the role of the host diet leads to improving the morpho-biological parameters of *Trichogramma* which can enhance the success of biological control programs as an essential part of Integrated Pest Management (IPM). This contributes to achieving the Sustainable Development Goals (SDGs).

INTRODUCTION

In the current global agricultural scenario, several management tactics are employed, either alone or in association with other procedures to combat insect pests that produce economic damage to different crops. Among the control tactics is biological control. It can significantly reduce the impact of chemical insecticides on the environment and other side effects. The use of parasitoids as biological control agents can be highly effective, particularly, due to their high host specificity (Sani *et al*., 2016; Cherif *et al.,* 2021).

Recently, *Trichogramma* species have become the most widely used insect as natural enemy in the world because they are easy to mass-produce and to use against many important crop insect pests. *Trichogramma* wasps parasitize the eggs of butterflies and moths (Lepidoptera), eggs of flies (Diptera), beetles (Coleoptera), other wasps (Hymenoptera), true bugs (Heteroptera), and lacewings (Neuroptera) (Sarwar and Salman, 2015; Shah *et al*., 2015). *Trichogramma* helps in the early control of insect pests before economic damage occurs. Relatively economical mass-rearing and short life cycles make them available for use in several crop protection programs. Also, *Trichogramma* wasps are used by artificial releases for pest control (Salas Gervassio *et al*., 2019). It is a valuable alternative for the sustainable control of many insect pests on various crops, such as vegetable and tree crops, as well as stored products (Parsaeyan *et al*., 2020).

Natural hosts are widely used to rear large quantities of parasitoids providing enough hosts to parasitoids and the time plays a critical role in sustaining the mass-rearing system (King *et al*., 1985; Wang *et al*., 2021). Consequently, improving the rearing of the host can be considered as one of the fundamental steps in mass production.

Artificial diets are one of the best ways to obtain standardized insect sources in insect mass-rearing (Vanderzant, 1974; Singh, 1983; Cohen, 2001; and Wang *et al*., 2021). Evaluation of insect fitness on either natural or artificial diets has been achieved by several recent studies (Chi, 2020; Wang *et al*., 2021). The importance of a natural and artificial host diets as a key factor influencing the nutritional quality of host eggs and consequently the fitness of reared *Trichogramma* returns to laboratory studies which found that the body length of *Trichogramma* adult is dependent on the size of the host egg, which it developed in (Cherif *et al*., 2021).

So, the objectives of this study are to determine which diets natural or artificial are most effective for rearing *Trichogramma turkestanica* Meyer in *Galleria mellonella* and *Plodia interpunctella* hosts egg. It also aims to evaluate the impact of reared hosts eggs on the morpho-biological characteristics of *Trichogramma turkestanica* and their suitability for parasitism.

MATERIALS AND METHODS

Two hosts of *Trichogramma*, *i.e.*, the greater wax moth *Galleria mellonella* L., (Lepidoptera: Pyralidae), and the Indian meal moth *Plodia interpunctella* Hb., (Lepidoptera: Pyralidae) were reared naturally and artificially at the Biological Control Lab., Plant Protection Dept., Assiut University, Assiut, Northern Upper Egypt (375 km South of Cairo).

1-Rearing Techniques:

1.1-The Greater Wax Moth, *Galleria mellonella* (L.):

The initial stock of the greater wax moth was collected from different apiaries and transferred to the laboratory. It was reared for at least two generations before experimental studies. Steps of rearing on a natural medium were carried out as explained by Hosamani *et al*. (2017), while steps of rearing on an artificial diet were done according to Kulkarni *et al*. (2012).

1.2-The Indian Meal Moth, *Plodia interpunctella* (Hb.):

The Indian meal moth, *Plodia interpunctella,* larvae collected from infested dates. The larval stage was reared in plastic containers (1kg) containing 100 g of wheat flour and corn flour. The plastic containers were covered with muslin cloth and fastened with a rubber band. The culture was maintained at 23±2°C, 75±5% RH, and was reared for at least two generations before the experiment. Steps of rearing on a natural diet were carried out as explained by Bouayad *et al*. (2008) and Predojević *et al*. (2017), while steps of rearing on an artificial diet were done according to Kulkarni *et al*. (2012).

2-Effect of Rearing Media on The Immature Stages of *G. mellonella* and *P. interpunctella*

2.1-Egg stage:

Eggs (<24 hours old) were kept in separate containers and checked every 24 hours, and the incubation period (in days) and hatchability (%) were calculated.

2.2-Larval Stage:

Newly hatched larvae were transferred into a separate glass tube per larva (7.5×2.5 cm), covered with plastic wrap, and containing (5 g) of the two-host diet daily. Replicas were checked to calculate larval duration and survival percentage.

2.3-Pre-Pupal Stage:

Pre-pupal stages were transferred into a separate glass tube per one (7.5×2.5 cm), covered with plastic wrap. Replicas were checked to calculate pre-pupal duration and survival percentage.

2.4-Pupal Stage:

Newly formed pupae were collected on the same day of pupation, placed in a labeled glass tube (2.0×7.5 cm) (One pupa/tube), and plugged tightly with a piece of cotton, observed daily until adult emergence. Pupal duration and survival percentage were calculated.

2.5-Adult Stage:

Ten newly emerged moths were transferred on the same day of emergence to plastic containers, ten replicates, each with two adults (1♂+1♀). Daily observations were made to record adult longevity and fecundity.

3-Certain Life Table Parameters of *G. mellonella* and *P. interpunctella*:

Life table parameters, including gross reproduction rate or net reproduction rate, generation time, doubling time, and rate of increase were calculated according to Carey (1993).

3.1-Net Reproductive Rate (R0) = $\sum$ lx. Mx:

The ratio of individuals in a population at the start of one generation to the number at the beginning of the previous generation is measured in units of ♀/♀/generation.

3.2.Generation Time (T) =$\sum$lx.mx.x/$\sum$lx. Mx:

The mean time from the birth of the parent to the birth of offspring measured in days.

3.3-Intrinsic Rate of Increase (rm) = $Log_e (R_0)$/ T:

3.4-Doubling time (DT) = Log_e 2/rm:

The time required for a given population to double its numbers is measured in days.

3.5-Finite Rate of Increase (λ) = e^{rm} :

The number of times the population will multiply itself per unit of time, measured in units of female/female/day.

x = age of individuals in days

l_x = number of individuals alive at age (x) as a proportion of one

m_x = the number of female offspring per female in age interval (x)

4-Collecting and Rearing *Trichogramma* Parasitoid:

The egg parasitoid *Trichogramma* was collected from Qus province, Qena Governorate (26° 09' 51.05" N, 32° 43' 36.16" E). *Trichogramma* wasps were collected in glass tubes. It was identified by sequencing the *ITS2* region, which matches *Trichogramma turkestanica* Meyer in the GenBank under the accession number of MW459187.1 (Abdel-Galil *et al*., 2023). It was raised using the hosts eggs of *G. mellonella* and *P. interpunctella* which were artificially and naturally reared for two generations under laboratory conditions

(23±2°C, 75±5% RH, L 16:D 8) in the Biological Control Lab., Plant Protection Dept., Assiut University, Assiut, Egypt.

5-Effect of Rearing *Trichogramma turkestanica* on Different Insect Host's Eggs:

Mounting adults of egg parasitoid *T. turkestanica* were processed to be permanent specimens for abdominal female measurements using the methods applied by Abdel-Galil *et al*. (2018) and Abdel-Galil *et al*. (2023).

According to Greenberg and Leppla (2017), fecundity and body length in the mature female of *T. turkestanica* are positively associated. The body length of *T. turkestanica* adult females is measured from the front to the tip of the abdomen. However, in the present study, the length of the abdomen was only measured from the front of the abdomen to the tip and the abdominal area measurement to differentiate between *T. turkestanica* reared on different host's eggs. Also, the measuring unit was changed from (mm) to (μm).

6-Evolution of the Quality of Host's Eggs on *T. turkestanica* under Laboratory Conditions:

Mated females of *T. turkestanica* parasitoid were singly transferred to Eppendorf Safe-Lock Tubes (2.0 mL). Fresh eggs from hosts that were reared on both natural and artificial diets, *G. mellonella* and *P. interpunctella*, were exposed to the females of *T. turkestanica* parasitoid (20 eggs /*Trichogramma* female) (n= 10).

Experiments were conducted under incubation conditions of 23±2°C and 70±5 RH % for 24 hours. Female parasitoids were removed from the tubes, and the parasitized eggs were incubated. After five days, eggs were examined for initial parasitism (black eggs). Then, daily examinations were conducted until adult parasitoid emergence.

7-Analysis of Data:

Data were expressed as mean ± SE and were statistically subjected to a one-way analysis of variance by Statistix 8.1 software (Analytical software, 2003).

RESULTS AND DISCUSSION

1-Effect of Natural And Artificial Diets on The Immature Stages:

The design of Integrated Pest Management (IPM) programs depends on characterizing and measuring biological factors, nutritional needs, and insect behavior. These studies are made possible for the insects for mass rearing in laboratories. The diet was able to support development that is comparable to that of natural foods as reported by Marzban *et al*. (2001), Razazzian *et al*. (2015), and Kandel *et al* (2020).

Data in Table 1, show the effect of different diets on the duration of immature stages and longevity of *G. mellonella* and *P. interpunctella*. The results indicate that immature stage periods differed in both diets and hosts except for the egg incubation period.

Table 1: Duration of immature stages (mean ± SE) and longevity of *Galleria mellonella* and *Plodia interpunctella* reared on different diets.

Host	Duration means (in days) ± SE				Total immature stages	longevity
	Egg stage	Larval stage	Pre-pupal stage	Pupal stage		
Galleria* A	9.68±0.054[a]	17.43±0.19[c]	1.56±0.097[d]	9.09±0.14[b]	37.56±0.32[c]	5.96[a]
Galleria* N	9.86±0.056[a]	32.21±0.20[a]	5.56±0.107[a]	16.51±0.16[a]	64.47±0.36[a]	5.97[a]
***Plodia* A**	8.85±0.054[b]	11.67±.21[d]	2.16±0.10[c]	7.04±0.17[d]	29.70±0.36[d]	5.33[b]
***Plodia* N**	8.84±0.054[b]	20.33±.21[b]	4.33±0.105[b]	7.9±0.16[c]	40.29±0.36[b]	5.36[b]

Means in a column followed by the same letter are not significantly different at 0.05 probability level.

*: ***A***, hosts reared on artificial diet, ***N***, hosts reared on natural diet**.**

The egg incubation period for *G. mellonella* reared on both nutritional diets was not different from each other (9.68±0.054 and 9.86±0.056 days for artificial and natural diets, respectively). Also, this period was not different for *P. interpunctella* (8.85± 0.054 and 8.84±0.054 days for artificial and natural diets, respectively).

However, comparing the two hosts, the egg incubation periods were different. The egg duration period is a very crucial criterion for the effectiveness of the parasitoid against the host. At the same time, it's important for parasitoid augmentation in the field, as the incubation period elongates giving the parasitoids more chances of parasitism than a short egg incubation period. These results are very interesting because the egg incubation period for the standard host (*Sitotroga cereallela* Oliv.) in lab rearing was 5 days, while these hosts recorded nine and ten-day egg incubation periods. The host eggs' age had a bigger effect on parasitism. These results agreed with Paraiso *et al*., (2012), who found that *T. fuentesi* parasitized on two-day-old host eggs, which was the most suitable host egg age for parasitism. Concurrently, *T. fuentesi* females continued the parasitism process until the 13-day-old host egg age of *Cactoblastis cactorum*. In our results, the host with the longest egg incubation period is recommended for *Trichogramma*.

The longest larval stage period was 32.21±0.20 days for *Galleria* A, followed by 20.33±0.21 and 17.43±0.19 days for *Plodia* N and *Galleria* A, respectively. Also, the shortest period was 11.67±0.21 days for *Plodia* A. However, the longest pre-pupal stage period was 5.56±0.107 days for *Galleria* N, followed by 4.33±0.105 and 2.16±0.10 days for *Plodia* N, and *Plodia* A respectively. Also, the shortest period was 1.56±0.097 days for *Galleria* A. In the pupal stage periods, the longest period recorded 16.51±0.16 days for *Galleria* N, followed by 9.09±0.14 and 7.9±0.16 days for *Galleria* A and *Plodia* N, respectively. However, the shortest period was 7.04±0.17 days for *Plodia* A. The longest total immature stage periods for both nutritional diets and hosts were 64.47±0.47days for *Galleria* N, and the shortest period was 29.70±0.36 days for *Plodia* A. These results indicate that *Plodia* A has the shortest immature stages which means many generations in a short period. Consequently, *Trichogramma* has many generations in a short period.

The longevity period for *G. mellonella* reared on both nutritional diets was not different (5.96 and 5.97 days for artificial (A) and natural (N) diets, respectively). Also, this period was not different for *P. interpunctella* (5.33 and 5.36 days for the artificial (A) and natural (N) diets, respectively). However, when comparing the two hosts, the period was significantly different.

According to the above-mentioned results, the total developmental period of the immature stages of the two hosts reared on artificial diets was shorter than that of the natural diet. Perhaps the components of the artificial diet have a positive effect on the growth and developmental stages of both hosts. Similar results were reported by Kandel *et al.,* (2020) who studied the effect of natural and artificial diets on the life duration of *G. mellonella* stages. The laboratory incubation period was 8.0±0.1, the larval stage was 37.10±1.4, the pupal stage was 12.41±1.7, and longevity was 25.33±2.8. In this respect, Marzban *et al*. (2001) recorded that the egg, larval, pupal, and adult developmental periods of *P. interpunctella* at 27±1 °C, 50–60% relative humidity, on pistachio with an average of 2.5, 31.08, 8 and 7 days, respectively.

Data presented in Table 2, indicate that the highest percentage of hatchability was recorded for *Galleria* A, *Plodia* A, and *Plodia* N (80%), whereas the lowest was recorded for *Galleria* N (76%). The embryogenesis data show that *Galleria* A, *Plodia* A, and *Plodia* N were the most suitable hosts for the completion of the embryogenesis.

Table 2: Survival of the immature stages of *Trichogramma turkestanica* hosts reared on different diets.

Host	No. of observation	Survival (%)				
		Hatchability	Larva	Prepupa	pupa	Egg to adult emergence
***Galleria* A**	50	80	95	94	91	62
***Galleria* N**	50	76	92	85	90	48
***Plodia* A**	50	80	85	88	90	48
***Plodia* N**	50	80	85	91	90	48

The population parameters, such as generation time (T), doubling time (DT), net reproductive rate (R_0), the intrinsic rate of increase (r_m), and the finite rate of increase (λ) are shown in Table 3.

The longest generation time (T) was recorded for *Galleria* N (65.91days) > *Plodia* N (41.85 days) > *Galleria* A (38.92 days), while the shortest generation time was recorded for *Plodia* A (30.98 days). The doubling time (DT) was affected by different diets. The descending order of the doubling time was *Galleria* N (8.77 days) > *Plodia* N (6.41 days) > *Galleria* A (4.62 days), while the lowest value was recorded for *Plodia* A (4.08 days). The highest net reproductive rate (R_0) was recorded for *Galleria* A (379.05 days) followed by *Galleria* N (186.07 days), and *Plodia* A (188.45 days) while the lowest was recorded for *Plodia* N (94.89 days). The highest Intrinsic rate of increase (r_m) was recorded for *Plodia* A (0.169 days) followed by *Galleria* A (0.15 days) > *Galleria* N (0.079 days) > and *Plodia* N (0.108 days). The highest Finite rate of increase (λ) was recorded for *Plodia* A (1.18 days), followed by *Galleria* A (1.16 days) > *Plodia* N (1.11 days) > while the lowest was recorded for *Galleria* N (1.08 days).

In this respect, Kandel *et al* (2020) studied the effect of natural and artificial food on the life table parameters of *G. mellonella*. The net reproductive rate (R_0) was recorded 49.4 and 31.5 days. However, mean generation time (T) was 57.4 and 68.4 days. The intrinsic rate of increase (r_m) recorded 0.07 and 0.05 days. The finite rate of increase (λ) recorded 1.07- and 1.05-days. Time of population doubling (DT) was recorded 10.5 and 14.7 days. Also, Razazzian *et al*. (2015) studied the life table parameters of *Plodia interpunctella* which reared on four commercial pistachio cultivars. He found that the intrinsic rate of increase (r_m) ranged from 0.0961 to 0.1382 (female/female/day) on Kalehghouchi and Akbari, respectively. The mean generation time (T) was found to be 35.67 and 31.83 days on Kalehghouchi and Akbari, respectively.

Table 3: Certain life table parameters of hosts reared on different diets.

Hosts	Generation time (T) (In days)	Doubling Time (DT) (In days)	Net Rep. Rate (R_0)	Rate of increase	
				Intrinsic (r_m)	Finite (λ)
***Galleria* A**	38.92	4.62	379.05	0.150	1.16
***Galleria* N**	65.91	8.77	186.07	0.079	1.08
***Plodia* A**	30.98	4.10	188.45	0.169	1.18
***Plodia* N**	41.85	6.41	94.89	0.108	1.11

By discussing the above-mentioned results obtained from life table parameters, the artificial diet is better than the natural diet for rearing *G. mellonella* and *P. interpunctella* in the laboratory, and the short life cycle in generation periods thus makes them available for using in the biological control programs.

2. Effect of Rearing *Trichogramma turkestanica* on Different Insect Host's Eggs:

2.1. Morphological Features:

2.1.1. The Measurements of *Trichogramma turkestanica* Female Abdomen from *Galleria mellonella and Poldia interponctella* Eggs Reared Naturally (N):

Data in Table 4, indicate that the length of the *Trichogramma turkestanica* female abdomen produced from *Galleria* eggs (N) measured from the front to the tip reached 322.141±11.92µm. Also, the average abdominal area reached 65291.4±2858.43µm^2 (Fig. 1a), while in *Plodia* eggs (N), the length of *Trichogramma turkestanica* female abdomen was 217.64±12.58µm and the average abdominal area reached 37543.72±4961.96µm^2 (Fig. 1b).

2.1.2. The Measurements of *Trichogramma turkestanica* Female Abdomen from *Galleria mellonella* and *Poldia interponctella* Eggs Reared Artificially (A):

Data in Table 4, indicate that the length of the *Trichogramma turkestanica* female abdomen produced from *Galleria* eggs (A) was 390.263±7.86µm. Also, the average abdominal area reached 79936.208±1530.53µm^2 (Fig. 1c), meanwhile, in *Plodia* eggs (A), the length of *Trichogramma turkestanica* female abdomen was 271.72±5.79µm and the average abdominal area reached 56854.51±416.70µm^2 (Fig. 1d).

Table 4: Abdominal length (µm), and abdominal area (µm²) measurements of female *Trichogramma turkestanica* on *Galleria* N, *Poldia* N, *Galleria* A, and *Poldia* A eggs

Criteria n=10	Female Abdomen Measurements							
	Abdomen length (µm)				Abdominal Area (µm²)			
	Min.	Max.	Mean	± SD	Min.	Max.	Mean	± SD
***Galleria* N**	311.79	351.9	322.14	11.92	61399.02	69813.04	65291.4	2858.43
***Podia* N**	200.01	238.04	217.64	12.58	30953.36	44653.72	37543.72	4961.96
***Galleria* A**	377.92	402.02	390.26	7.86	76329.57	82645.59	79936.2	1530.53
***Podia* A**	260.09	279.21	271.72	5.79	56100.29	57211.5	56854.51	416.7

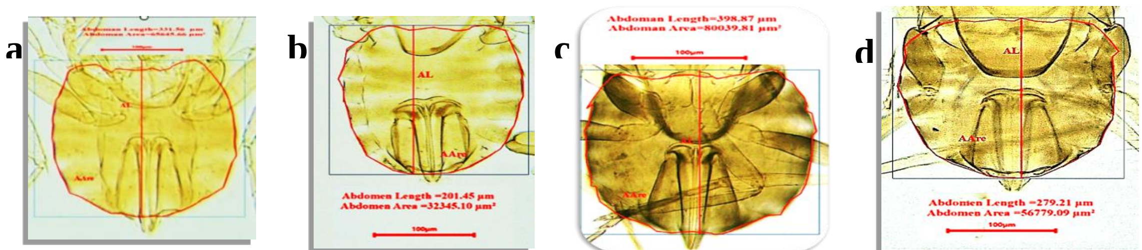

Fig. 1: The abdomen of *Trichogramma turkestanica* female reared on different hosts: a, b Galleria *and Plodia* eggs nurtured naturally and c, d *Galleria and Plodia* eggs nurtured artificially, respectively.

The above-mentioned results of morphological features of *Trichogramma turkestanica* female evaluate the efficacy of rearing *Trichogramma turkestanica* on *Galleria mellonella* and *Plodia interpunctella* eggs naturally and artificially under laboratory conditions to select the best host for rearing *Trichogramma turkestanica* for biological control.

Three among five egg types of female abdominal measurements reared naturally and two reared artificially were shown (Table 5 and Fig. 2). The measurement includes abdominal length (Abdo. Length (µm)) and abdominal area (Abdo. Area (µm^2)). The highest values of abdominal length and abdominal area were produced from *Galleria* A eggs

(390.263 ±7.86 µm and 79936.208±1530.53 µm^2)followed by *Galleria* N (322.141±11.92 µm and 65291.4±2858.43 µm^2), *Plodia* A (271.72±5.79 µm and 56854.51±416.70 µm^2), *Sitotroga* N (245.98±12.47 µm and 43274.3±5031.23 µm^2) while the less values was for *Plodia* N eggs (217.64±12.58 µm and 37543.72±4961.96 µm^2) (Fig. 2).

Statistical analysis of the data indicates a highly significant difference between the five types of eggs (F = 142.56** and 243.66** for Abdominal Length and Abdominal Area, respectively).

According to Greenberg and Leppla (2017) fecundity and body length in mature female *Trichogramma* are positively associated. *Trichogramma* adult females are classified into four quality groups based on the length of their bodies measured from the tip of their abdomen to the front as follows: Class 1 >0.421 mm, Class 2 from0.290 to 0.420 mm, Class 3 from 0.188 to 0.289 and Class 4 <0.187 mm (Non-standard).

In the present study, the length of the abdomen was only measured from the front of the abdomen to the tip to differentiate between *T. turkestanica* reared on different host's eggs. Also, the length of female abdomen measurement is classified into four quality groups as follows: Class 1 > 401µm, Class 2 from 311 to 400 µm, Class 3 from 200 to 310 µm and Class 4 <199 µm (Non-standard). Concerning to the area of female abdomen measurement is classified into five quality groups as follows: Class 1 > 82644µm^2, Class 2 from 69813 to 82643 µm^2, Class 3 from 48221 to 69812 µm^2, Class 4 from 30953 to 48220µm^2 and Class5 <30952 µm^2 (Non-standard).

The length of female abdomen measurement values of the five hosts eggs naturally and artificially *Galleria* A, *Galleria* N, *Sitotroga* N, *Plodia* A, and *Plodia* N were 390.263, 322.141, 271.72, 245.98, 217.64 µm, respectively. So, the *Galleria* A and *Galleria* N (390.263, 322.141, µm) are considered in class 2 (311 - 400 µm,) while *Plodia* A, *Sitotroga* N, and *Plodia* N belong to Class 3 (200 - 310 µm) (271.72, 245.98, 217.64µm).

Concerning to the area of female abdomen measurement values of five hosts eggs naturally and artificially *Galleria* A, *Galleria* N, Plodia A, *Sitotroga* N, and *Plodia* N were 79936.2, 65291.4, 56854.51, 43274.3, and 37543.72 µm^2. So, the *Galleria* A (79936.2µm^2) is considered in class 2 (69813 - 82643 µm^2). While the *Galleria* N and *Plodia* A (65291.4, 56854.51µm^2, respectively) are considered class 3 (48221 - 69812 µm^2). However, the *Sitotroga* N, and *Plodia* N (43274.3, 37543.72 µm^2, respectively) are considered class 4 (30953 - 48220µm^2)

By discussing the above-mentioned results concerning morphological features of ***T.*** *turkestanica* females produced from eggs of *Galleria* A and *Galleria* N (Artificially and Naturally) is the best host to reared *Trichogramma turkestanica* under laboratory conditions followed by *Plodia* A, *Sitotroga* N, and *Plodia* N.

It is important to point out herein that the size of the host female is an important quality parameter for selecting the best host for mass-rearing *Trichogramma* in the Biological Control Lab.

Table 5: *Trichogramma turkestanica* female abdominal measurements reared on different insect host's eggs.

Criteria (N=10)	***T.** turkestanica* **Female Abdominal Measurement (Mean ± SD)**					**F value**
	***Galleria* A#**	***Galleria* N#**	***Plodia* A**	***Plodia* N**	***Sitotroga* N**	
Abdo. Length (µm)	390.263 ±7.86$^{a\#}$	322.141 ±11.92^{b}	271.72 ±5.79^{c}	217.64 ±12.58^{e}	245.98 ±12.47^{d}	142.56**
Abdo. Area (µm^2)	79936.208 ±1530.53^{a}	65291.4 ±2858.43^{b}	56854.51 ±416.70^{c}	37543.72 ±4961.96^{e}	43274.3 ±5031.23^{d}	243.66**

Means having the same letter in a column are not significant at 5% level of probability according to Duncan's multiple range test.

#: ***A*** hosts reared on artificial diet, ***N***, hosts reared on natural diet

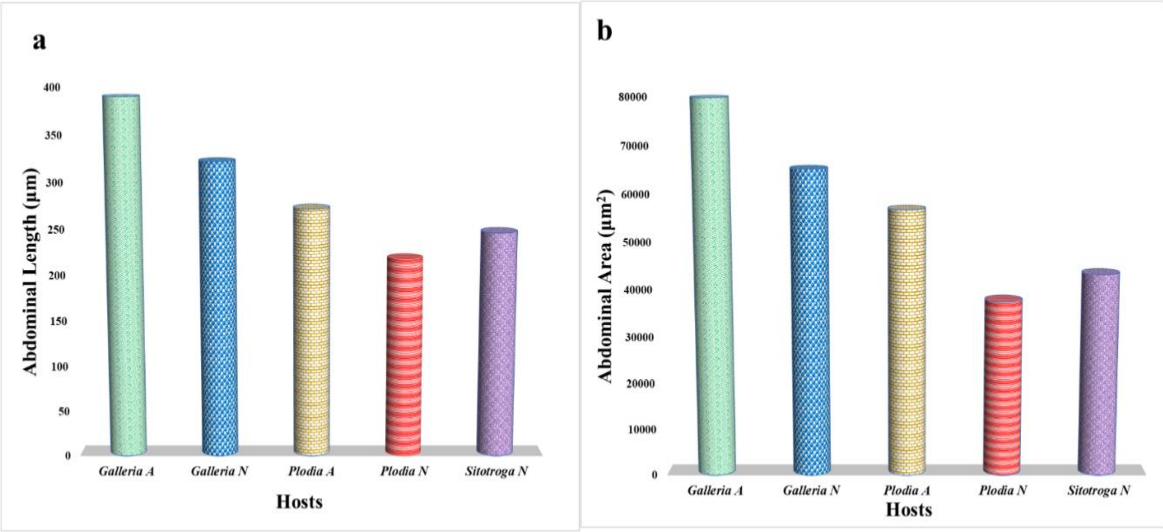

Fig. 2: a) Female abdominal lengths and **b)** Female abdominal area for the *Trichogramma turkestanica* hosts **(***N*, hosts reared on a natural diet, *A*, hosts reared on an artificial diet)

3-Host Egg Suitability for *T. turkestanica:*

The current results show the suitability of the two-host eggs for *Trichogramma turkestanica* under laboratory conditions (25±2°C, 70±5% RH), as the hosts were reared on different diets, natural and artificial. The hosts were *G. mellonella* reared on natural wax combs and reared on an artificial diet and *P. interpunctella* which was reared on whole grain corn flour and the same artificial diet as *G. mellonella.*

Biological criteria include percentages of parasitism (=successful parasitized eggs), Hatched parasitized eggs, emerged adult parasitoids, and emerged female parasitoids. Twenty eggs per *Trichogramma* female were replicated ten times. *Galleria* N, *Galleria* A, *Plodia* N, and *Plodia* A (egg age < 24 hour-old). Data in Table 6, show the effect of the host egg on the percentage of successful parasitized eggs, emerged adult parasitoids from parasitized eggs, and emerged female parasitoids for the tested hosts, *Galleria* N, *Galleria* A, *Plodia* N, and *Plodia* A. The minimum percentage of successful parasitized eggs for *Plodia* A was 78.5±13.75%, while the maximum mean percentage of successful parasitized eggs was 94±6.43% for *Galleria* A. However, the successfully parasitized eggs of *Galleria* N and *Plodia* N were 84±12.20%. The percentage of emerged adults from parasitized eggs was affected significantly (F =3.30*) with a maximum mean of 95.39±6.49 % for *Galleria* A. The percentages of emerged adult parasitoids from parasitized eggs for *Galleria* N and *Plodia* N were the same (87.35±10.31%), while the minimum for *Plodia* A was 85.28±12.41%.

Emerged female parasitoids were not affected ($F = 1.47^{ns}$). The maximum mean was 69.97±8.85% for *Galleria* A, followed by *Plodia* N with a mean of 63.28±4.19%, then *Galleria* N with a mean of 62.78±3.78% and the minimum was for *Plodia* A with a mean of 61.79±3.97%.

T**able 6:** Biological criteria of host's egg suitability for *Trichogramma turkestanica*

Hosts	**Host density. (n =10)**	**Parameters%**			
		Successful parasitized eggs	**Hatched parasitized eggs**	**Emerged adult parasitoids**	**Emerged female parasitoids**
***Galleria* A#**	**Min.**	80	80	100	53
	Max.	100	100	115	82
	Mean ±SD	94.5±6.43[a]	95.39±6.49[a]	102.12±4.93[a]	69.97±8.85[a]
***Galleria* N#**	**Min.**	70	75	100	56
	Max.	100	100	115.38	66
	Mean ±SD	84±12.20 [a]	87.35±10.31[b]	103.16±5.48[a]	62.78±3.78[a]
***Plodia* A**	**Min.**	60	69.23	100	55
	Max.	100	100	166.66	66
	Mean ±SD	78.5±13.75 [b]	85.28±12.41[b]	111.94±21.57[a]	61.79±3.97[a]
***Plodia* N**	**Min.**	70	75	94.11	56
	Max.	100	100	115.38	68
	Mean ±SD	84±12.20 [a]	87.35±10.31[b]	102.57±6.13[a]	63.28±4.19[a]
F value		3.38*	3.38*	3.30*	1.47[ns]

Means having the same letter in a column are not significant at 5% level of probability according to Duncan's multiple range test.
#: ***A***, hosts reared on artificial diet, ***N***, hosts reared on natural diet

From these results, it can be concluded that the parameter % varied between the tested hosts. So, *Galleria* A appeared as the best host with successful parasitized eggs, emerged adult parasitoids from parasitized eggs, and emerged female parasitoids.

It can compare with the above-mentioned results with those obtained by many authors who use *G. mellonella* and *P. interpunctella* for mass rearing of *Trichogramma* but do not study host-parasite relationships, such as Haque *et al*. (2021), they study the cold storage-mediated rearing of *T. evanescens* on eggs of *P. interpunctella* and *G. mellonella*.

In conclusion, it is of interest to point out herein that the role of the host diet in the development and on the other morphological parameters of *Trichogramma turkestanica* can improve the success of biological control programs as an essential part of Integrated Pest Management (IPM). Of which will contribute to achieving the Sustainable Development Goals (SDGs).

List of Abbreviation

Full name	**Abbreviation**
Artificial diet	**A**
Doubling time	**DT**
Finite rate of increase	**λ**
Generation time	**T**
Integrated Pest Management	IPM
Intrinsic rate of increase	**rm**
Natural diet	**N**
Net reproductive rate	$\mathbf{R_0}$
Sustainable Development Goals	**SDGs**

Declarations:

Ethical Approval: Ethical Approval is not applicable.

Authors Contributions: Dr. Farouk A. Abdel-Galil and Dr. Mervat A. B. Mahmoud made a great effort in the technique of the experiment. Dr. Sara E. Mousa and Ms. Aya A. M. Ahmed made great efforts to breed different the stages of insect hosts and egg parasitoid *Trichogramma turkestanica* used in this experiment. Dr. Farouk A. Abdel-Galil, Ms. Aya A.

M. Ahmed, Dr. Sara E. Mousa, Dr. Mervat A. B. Mahmoud, Dr. Mohammad Allam, and Dr. Nesreen M. F. Abou-Ghadir were a major contributor to the manuscript writing. Dr. Mohammad Allam and Dr. Sara E. Mousa made the Revion of the manuscript. All authors read and approved the final manuscript.

Competing Interests: The authors declare that they have no competing interests.

Availability of Data and Materials: The data supporting this study findings are available from all authors upon reasonable request.

Source of Funding: The current research was not funded.

Acknowledgements: We are grateful to everyone who contributed to this valuable work to come out this way. We thank the Biological Control Unit of the Plant Protection Department, which was established in 2004 by F. A. Abdel-Galil.

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ARABIC SUMMARY

تأثير تربية دودة الشمع الكبيرة وفراشة الدقيق الهندية طبيعيا وصناعيا على جوانبها البيولوجية والخصائص المورفوبيولوجية للترايكوجراما تركستانيكا

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أجريت هذه الدراسة بهدف تأكيد ما إذا كانت النظم الغذائية الصناعية أو الطبيعية هي الأفضل لتربية العوائل الحشرية مثل دودة الشمع الكبيرة وفراشة الدقيق الهندية لتربية طفيل البيض التريكوجراما تركستانيكا. وكذلك تأثير بيض العوائل المرباة على الصفات المورفولوجية والبيولوجية لطفيل الترايكوجراما ومدى ملاءمتها للتطفل.

أظهرت نتائج معايير جداول الحياة أن أقصر زمن جيل وأقل زمن مضاعفة (DT) تم تسجيله لـفراشة الدقيق الهنديةA ، في حين أن أعلى معدل تكاثر صافي (R0) كان لـ دودة الشمع الكبيرة A . لذا فإن هذه المعايير للنظام الغذائي الصناعي أفضل من النظام الغذائي الطبيعي لتربية دودة الشمع الكبيرة وفراشة الدقيق الهندية في المعمل، كما ان دورة الحياة القصيرة للأجيال تجعلها مفضلة للاستخدام في تربية طفيل الترايكوجراما كعامل مكافحة بيولوجية.

النتائج المتعلقة بالصفات المورفولوجية لإناث طفيل الترايكوجراما التي تمت تربيتها على بيض دودة الشمع الكبيرة المتغذية على الأنظمة الغذائية الصناعية والطبيعية كانت أفضل العوائل تحت الظروف المعملية. ويليها فى ذلك كل من وفراشة الدقيق الهندية A وفراشة الحبوب N ثم فراشة الدقيق الهندية N .

كما أثبتت النتائج التي تم الحصول عليها أن أعلى متوسط لنسبة التطفل الناجح وأعلى نسبة لظهور لإناث طفيل الترايكوجراما كانت لـ دودة الشمع الكبيرة A . وبالمقارنة، فإن معدل ظهور الحشرات ا الكاملة من البيض المتطفل عليه كان لـ وفراشة الدقيق الهنديةA .

ومن المثير للاهتمام أن نشير هنا إلى أن دور النظام الغذائي للعائل يؤدي إلى تحسين المعايير المورفوبيولوجية للتريكوجراما ويمكن أن يعزز نجاح برامج المكافحة الحيوية كجزء أساسي من الإدارة المتكاملة للآفات (IPM). ويساهم في تحقيق أهداف التنمية المستدامة (SDGs).

الكلمات المفتاحية: دودة الشمع الكبيرة، فراشة الدقيق الهندية، نظام غذائي صناعي، ترايكوجراما تركستانيكا.