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Life table and biological studies of *Harmonia axyridis* Pallas (Col., Coccinellidae) reared on the grain moth eggs of *Sitotroga cerealella* Olivier (Lep., Gelechiidae)

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Abstract: The developmental period of immature stages, survival per cent, longevity, fecundity and life table parameters of *Harmonia axyridis* by feeding on fresh and frozen grain moth eggs (GME) of *Sitotroga cerealella* were studied under laboratory conditions. The effect of crowding adults on fecundity of females was also determined. The total developmental time from egg hatching to adult eclosion ranged from 18.89 ± 0.32 to 22.5 ± 0.21 days on fresh and frozen GME, respectively. Survival per cent from egg hatching to adult emergence differed significantly when the predator fed on the two diets of GME. Also, pupal and adult weights were affected by feeding on fresh and frozen GME. There were no significant differences in longevity of females, while there were significant variations in fecundity of females and longevity of males. The calculated values of T, DT, R_o, r_m, and e^{rm} were high by feeding on fresh GME. Morever, rates of survivorship (Lx), and maximum oviposition per female per day (Mx) were higher when the predator was reared on fresh than on frozen GME. Crowding conditions of predator adults affected the fecundity of females due to egg cannibalism by both males and females of the predator.

1 Introduction

The multicoloured Asian ladybeetle, *Harmonia axyridis* Pallas is an important non-specific predator of many insect pests (McClure, 1987; Chapin and Brou, 1991; Abdel-Salam, 1995; Ellington et al., 1995; Brown and Miller, 1998). It could make a good candidate for mass rearing and release in pest hot spot infestations in open fields and greenhouses, because it has a good search activity and a high consumption rate (Tedders and Schaefer, 1994 and Ferran et al., 1997). Although, it originated in Japan, Korea, Formosa, China and other parts of Asia (Chapin, 1965), due to the efficieny of *H. axyridis*, the predator has been imported to many countries (i.e. France, USA, Greece, Egypt and Syria) (Gordon, 1985; Ongagna et al., 1993; Abdel-Salam, 1995; Ghanim and El-Adl, 1996; Abdel-Salam et al., 1997a, 1997b; Icarda, 1997; Katsoyannos et al., 1997; El-Arnaouty et al., 1998). It has not been yet recorded in the Egyptian fauna (Tawfik, 1997).

In order to use this predator in pest management programmes, it is necessary to develop a mass production method. Factitious preys or hosts are insects not normally attacked by an entomophagous insect, but which are suitable for this purpose. These prey comprise immature or adult stages offered either alive or dead by freezing or exposure to UV radiation, and are often easier and less expensive to rear than the natural preys (Waage et al., 1985; Schanderl et al., 1988; Greco and Stilinovic, 1998). The angoumois grain moth eggs (GME) of *Sitotroga cerealella* Olivier have been used as factitious hosts for mass production of Trichogrammatidae (Hassan, 1981; Abbas et al., 1989) and several insect predators (e.g. *Chrysoperla rufilabris* Burmeister, *Orius majusculus* Reuter and *Leis dimidiata* Fabr.) (Legaspi et al., 1994; Semyanov, 1996; Hejzlar and Kabicek, 1998).

Life table parameters are essential when studying the general biology of an insect. From these parameters, the intrinsic rate of natural increase (r_m) is regarded as the best available single description of the population growth of a species under given conditions (Southwood, 1978). It can be determined by the insect's developmental time and reproduction rate. The r_m has been used to compare a species under different environmental conditions and as an index of population rate response to selected preys.

Scanty information is available concerning the suitability of fresh and frozen angoumois GME of *S. cerealella* as prey for mass rearing of *H. axyridis*, the effect of these diets on the biology and life table, and the influence of crowding adults on fecundity of females. Therefore, the objective of the current study was to investigate the suitability of fresh and frozen angoumois GME of *S. cerealella* as factitious preys for rearing *H. axyridis*, the effect of these diets on the biological characters of this predator, the influence of the above diets on life table parameters, and the effect of crowding adults on the fecundity of the predator female.

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2 Materials and methods

2.1 Rearing immature stages of *H. axyridis*

H. axyridis adults were obtained in October 1994 from New Mexico State University, Las Cruces, NM, USA. They were reared on the cotton aphids, *Aphis gossypii* Glover, and released in the open fields at the Experimental Research Station, Mansoura University, Egypt (Abdel-Salam, 1995). The eggs laid by females were removed daily and monitored until hatching. To avoid cannibalism, the hatched larvae of this predator were reared individually in Petri dishes (9 cm in diameter). A piece of filter paper was placed on the bottom of each dish to provide a walking surface for the larvae. Twenty-five *H. axyridis* larvae were reared on fresh or frozen (i.e. killed in a freezer to prevent egg hatching) GME of *S. ceralella* Olivier that were reared according to the method described by Hassan (1981) and Abbas et al. (1989). Each reared larva was considered to be a replicate. The developmental time of immature stages, survival from eggs to adult eclosion and sex ratio were recorded. Pupal and adult stage body weights were also determined.

2.2 Rearing *H. axyridis* adults

After eclosion, 20 males and 20 females of *H. axyridis* were also fed on the diets of GME until death. The duration of the preoviposition, oviposition and postoviposition periods, the fecundity of female and the longevity of males was recorded. The effect of the two diets on life table parameters was calculated using a BASIC computer program (Abou-Setta et al., 1986) for females reared on both diets. This computer program is based on Birch's (1948) method for the calculation of an animal's life table. Effect of factitious preys on population growth of the predator was assessed by constructing a life table, using rates of age-specific (Lx) and fecundity (Mx) for each age interval (x). To compare the biotic potential of the predator fed on fresh or frozen GME, the following population growth parameters were determined: the mean generation time (T), the net reproductive increase (R_o), the intrinsic rate of increase (r_m), and the finite rate of increase (e^{rm}). The doubling time (DT) was calculated according to Mackauer's (1983) method. The life tables were prepared from data recorded daily on developmental time (egg to first egg laid), sex ratio, the number of deposited eggs, the fraction of eggs reaching maturity and the survival of females. One-day intervals were chosen as the age classes for constructing the life table.

2.3 Effect of crowding on the fecundity of females

Predator adults were divided into four treatments, each of which had four replicates: first treatment, 10 males and 10 females; second treatment, 20 males and 20 females; third treatment, 30 males and 30 females; fourth treatment, 40 males and 40 females. Plastic containers (24 × 16 × 11 cm) were used as rearing units for each replicate. Paper strips were criss-crossed in layers to minimize egg cannibalism by both males and females, and to serve as oviposition sites. Each container was covered with muslin tightened with a rubber band. A surplus of fresh GME were distributed in the containers for feeding. Twenty-five pairs of *H. axyridis* were reared in Petri dishes as checks. The number of eggs was counted daily for a 30-day observation period; the highest oviposition rate of *H. axyridis* was generally reached within this period when there was a high food supply (Abdel-Salam et al., 1997b). All of the experiments were run in an incubator set for a constant temperature of 27.0 ± 1.0°C, 75.0 ± 5.0% relative humidity (RH) and 16 h light : 8 h dark.

2.4 Data analysis

Data for developmental time of immature stages, survival, weight of pupae and adults, longevity and fecundity of females, and longevity of males reared on fresh or frozen GME were subjected to one-way analysis of variance (anova), and the means separated using Duncan's Multiple Range Test (Costat, 1990).

3 Results

3.1 Developmental times of immature stages

The anova indicated that there were no statistically significant variations in the incubation period of *H. axyridis* eggs when females were reared on fresh and frozen GME (table 1). Also, data in the same table showed that the average developmental time of the four larval instars was 2.34 ± 0.18, 2.00 ± 0.10, 2.95 ± 0.11 and 3.90 ± 0.08 days, respectively, when larvae were fed on fresh GME. When fed on frozen GME, the developmental time was 3.04 ± 0.12, 2.47 ± 0.09, 3.09 ± 0.10 and 4.80 ± 0.19 days, respectively, with no significant difference. The developmental time of larval and pupal stages was 11.19 ± 0.14 and 4.9 ± 0.10 days, respectively, on fresh GME. However, on frozen GME, the developmental time of larval and pupal stages was 13.4 ± 0.17 and 6.0 ± 0.21 days, respectively, with no significant differences. Based on statistical analysis, the duration from egg hatching to adult eclosion was significantly different between fresh and frozen GME. Survival per cent from egg to adult *H. axyridis* varied from 84% on fresh to 80% on frozen GME (table 1). The average pupal and adult body weights were 27.72 ± 1.22 mg and 26.79 ± 1.12 mg, respectively, when larvae were fed on fresh GME. On frozen GME, the body weights were 24.53 ± 1.39 and 23.14 ± 1.65 mg, respectively, with significant variation between the two diets (table 2).

3.2 Longevity and fecundity of adult stage

Average longevity and fecundity of *H. axyridis* adults fed on the two diets of GME is given in table 3. Preoviposition periods were shorter when females were reared on fresh GME (8.1 ± 0.31 days), while this period lasted 9.5 ± 0.52 days on frozen GME. There were significant differences between oviposition periods when reared on the two diets of GME, whereas no significant variation has been noted in either postoviposition period or the total longevity of females (table 3). Concerning the fecundity of females, the average number of eggs per female fed on the two diets of GME varied from 715.3 ± 33.62 (fresh) to 606.6 ± 21.87 (frozen GME), respectively, with a significant difference.

Table 1. *Duration of the developmental stages of* H. axyridis *reared on fresh and frozen grain moth eggs under laboratory conditions*

Diet	Incubation period (mean ± SE)	Larval instars duration (mean ± SE)[a]					Pupal stage (mean ± SE)	Total duration (from egg to adult) (mean ± SE)	Survival (%)
		1st	2nd	3rd	4th	Total			
Fresh GME	2.8 a ± 0.10	2.34 a ± 0.18	2.00 a ± 0.10	2.95 a ± 0.11	3.90 a ± 0.08	11.19 a ± 0.14	4.9 a ± 0.10	18.89 b ± 0.32	84 a
Frozen GME	3.1 a ± 0.11	3.04 a ± 0.12	2.47 a ± 0.09	3.09 a ± 0.10	4.80 a ± 0.19	13.4 a ± 0.17	6.0 a ± 0.21	22.5 a ± 0.21	80 b

[a]Means followed by the same letter in a column are not significantly different at the 1% level of probability (Duncan's Multiple Range Test).

Table 2. *Weight of pupal and adult stages of* H. axyridis *when larvae reared on fresh and frozen grain moth eggs under laboratory conditions*

Diet	Pupal stage (mean[a] ± SE)	Adult stage (mean ± SE)
Fresh GME	27.72 a ± 1.22	26.79 a ± 1.12
Frozen GME	24.53 b ± 1.39	23.14 b ± 1.65

[a]Means followed by the same letter in a column are not significantly different at the 1% level of probability (Duncan's Multiple Range Test).

In addition, the results in table 3 showed that the average longevity of males was significantly longer by feeding on fresh than on frozen GME.

3.3 Life table parameters

Data presented in table 4 illustrate the life table parameters of *H. axyridis* females. The mean generation time (T) was shorter when the females were reared on fresh GME (37.87 days), while on frozen GME (T) was 45.04 days. The population of this predator could be doubled every 4.53 and 5.72 days when females were fed on the two diets. The value of net reproductive rate (R_o) was higher by feeding on fresh than on frozen GME. The higher values of the intrinsic rate of increase (r_m), and the finite rate of increase (e^{rm}) were achieved when the females were fed on fresh GME, whereas the lower values were obtained on frozen GME (table 4). From data illustrated in fig. 1, it could be noted that the survivorship (Lx) for female age intervals was high (0.84) on fresh GME, which means that most of the eggs had developed to maturity and death happened gradually after an extended ovipositional period. However, on frozen GME, the value of (Lx) was relatively low (0.80). Maximum oviposition rate per female per day (Mx) was 18.44 on the second day, and 17.44 on the eighth day when females were fed on fresh and frozen GME, respectively.

3.4 Effect of crowding on fecundity of females

The average number of eggs per *H. axyridis* female reared under crowding conditions and checked during the 30-day observation period is presented in table 5. It was interesting that there were significant differences between treatments reared under crowding conditions. Average number of eggs per female was 264.8 ± 43.03 in the first, 76.32 ± 53.99 in the second and 73.64 ± 56.96 in the third treatment, while the lowest number was achieved when adults were reared under the conditions of the fourth treatment (40 males and 40 females/container). However, adults reared individually in Petri dishes laid a higher number of eggs during the observation period than those reared under crowding conditions (table 5 and fig. 2).

In addition, the daily rate of oviposition per female fluctuated during the 30-day observation period under crowding conditions (fig. 2). This rate was influenced significantly by number of males and females in each

Table 3. *Longevity, and fecundity of* H. axyridis *adults reared on fresh and frozen grain moth eggs under laboratory conditions*

Diet	Sex	No.	Longevity (mean ± SE)[a] Preoviposition	Oviposition	Postoviposition	Total longevity	No. of eggs/female (Mean ± SE)
Fresh GME	M	20	–	–	–	47.5 A ± 1.31	–
	F	20	8.1 a ± 0.31	49.0 a ± 2.78	5.1 a ± 0.27	62.2 a ± 2.70	715.3 a ± 33.62
Frozen GME	M	20	–	–	–	43.9 B ± 2.05	–
	F	20	9.5 a ± 0.52	45.3 b ± 2.95	6.8 a ± 0.38	61.6 a ± 3.09	606.6 b ± 21.87

[a]Means followed by the same small or capital letter in a column are not significantly different at the 1% level of probability (Duncan's Multiple Range Test).

Table 4. *Life table parameters of* H. axyridis *fed on fresh and frozen grain moth eggs under laboratory conditions*

Diet	Initial no. of females	Mean generation time (T) (in days)	Doubling time (DT) (in days)	Net reproductive rate (R_o)	Intrinsic rate of increase (r_m)	Finite rate of increase (e^{r_m})
Fresh GME	20	37.87	4.53	289.11	0.153	1.166
Frozen GME	20	45.04	5.72	234.96	0.121	1.128

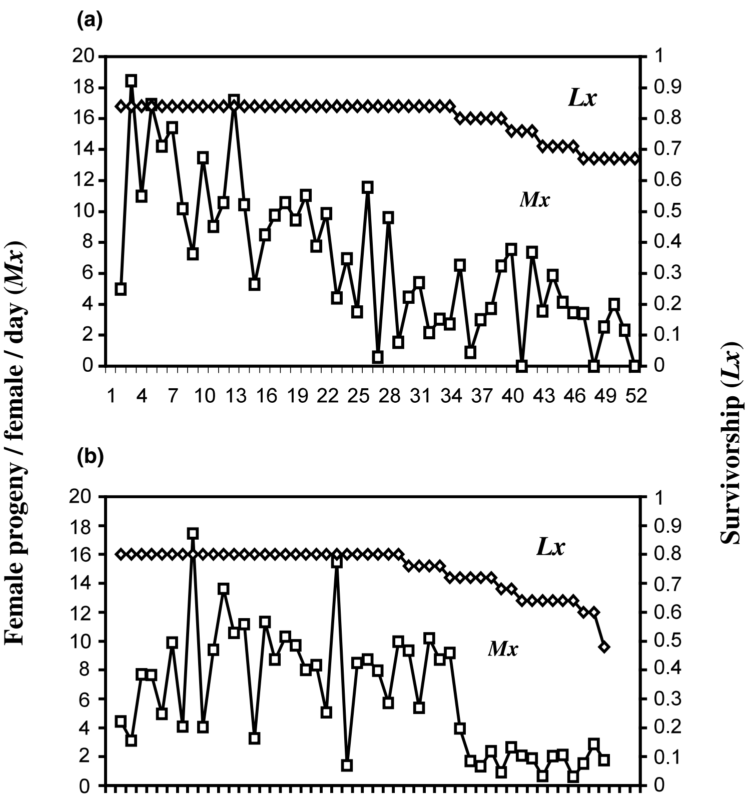

Fig. 1. *Age-specific fecundity (Mx) and survivorship (Lx) of* H. axyridis *reared on fresh and frozen grain moth eggs under laboratory conditions (a, fresh; b, frozen)*

treatment. The highest daily rate of oviposition was obtained when the adults were reared individually in Petri dishes, while the lowest one was achieved in the fourth treatment.

4 Discussion

In mass rearing of entomophagous insects for inoculative or inundative release, it may be more economical to develop artificial diets or use factitious preys (Waage et al., 1985). Artificial diets have been developed for both larvae and adults of many coccinellid predator species, but they are not yet suitable for use in mass production. Also, artificial diets that support normal rates of coccinellid egg production are not commercially available (Hagen, 1987; Hatting and Samways, 1993; Abdel-Salam et al., 1997a, 1997b; Obrycki and Kring, 1998). Focus on suitability of alternate or factitious preys is

Table 5. *Average number of eggs per* H. axyridis *female reared under crowded condition and check during 30 days of observation period under laboratory conditions*

Treatment	No. of females/container	Average[a] no. of eggs/female (± SE)
First	10	264.8 b ± 43.03
Second	20	176.32 c ± 53.99
Third	30	73.64 d ± 56.96
Fourth	40	46.54 e ± 43.57
Check	1	391.96 a ± 39.38

[a]Means followed by the same letter in a column are not significantly different at the 1% level of probability (Duncan's Multiple Range Test).

warranted (Obrycki and Kring, 1998). *Ephestia kuehniella* and *S. cerealella* eggs are widely used for rearing coccinellid, chrysopid and anthocorid species (Legaspi et al., 1994; Ferran et al., 1997; Hejzlar and Kabicek, 1998).

The developmental time of immature stages of *H. axyridis* reported in the current study follows a trend similar to those reported by Kim and Choi (1985) (19.92 days on *A. gossypii*), Niijima et al. (1986) (18.4 days on *Aphis rumicis* powder), McClure (1987) (18.6 days on *Acyrthosiphon pisum* Harris), Schanderl et al. (1988) (14.1–16.0 days on *Anagasta kuehniella* Zell. eggs killed by UV radiation), Brun (1993) (18.0 days on *E. kuehniella*), He et al. (1994) (18.07 days on *A. gossypii*), Abdel-Salam et al. (1997a) (13.59 and 17.55 days for developmental time of larval and pupal when the larvae fed on pink bollworm (PBW) eggs, *Pectinophora gossypiella* Saunders, and yellow pecan aphids (YPA), *Monelliopsis pecanis* Bissell), respectively, and Phoofolo and Obrycki (1998) (14.6 days from 1st instar larvae to adult eclosion on *A. pisum*).

Survival per cent was found to closely match that of Kim and Choi (1985) (85.9% on *A. gossypii*), Niijima et al. (1986) (80.0% on *Aphis rumicis* powder), Schanderl et al. (1988) (88.3% days on *A. kuehniella* eggs), and Abdel-Salam et al. (1997a) 88.0 and 90.0% on PBW and YPA, respectively. Similar results concerning pupal and adult weight were found by Niijima et al. (1986), Schanderl et al. (1988) and Abdel-Salam et al. (1997a).

The results of longevity and fecundity are in complete agreement with those addressed by Kim and Choi (1985), who found that the adult longevity was 31.4 days on *A. gossypii.* The average eggs per female on *A. pisum* was 718.7, preoviposition and oviposition periods were 7.3 and 45.2 days (McClure, 1987). Schanderl et al. (1988) reported that the fecundity was 522 eggs/female on *A. kuehniella* eggs. Brun (1993) mentioned that the females laid eggs after 8–10 days from emergence on *A. gossypii.* On *A. gossypii*, the preoviposition period was 13–30 days and females laid 751 eggs (He et al., 1994). Abdel-Salam et al. (1997b) found that the preoviposition, oviposition and postoviposition periods were 14.8, 49.0 and 37.0 days, respectively, on PBW eggs. The longevity of males was 65 days, and the number of eggs/female was 257.0. On Russian wheat aphid, *Diuraphis noxia*, and black bean aphid, *Aphis fabae*, the females laid a total of 1536 and 834 eggs/female, respectively (Icarda, 1997).

There are no published data on the life table parameters of *H. axyridis* on preys tested in the current study or other preys for comparison, whereas there were some investigations on life table parameters of other coccinellid predator species. Comparison between life table parameters of *H. axyridis* and other coccinellids showed that the shortest mean generation time (*T*) was recorded with *Stethorus picipes* Casey, *Coleomegilla maculata* DeGeer and *H. axyridis*, while the longest (*T*) was observed with *Rodolia iceryae* Janson (table 6). *H. axyridis* populations doubled in a shorter period than other coccinellid predators. The highest values of R_o, r_m and e^{rm} were recorded with *H. axyridis* and *Coccinella septempunctata* L. in comparison to other coccinellid predators. The calculated values of *DT* and r_m for *H. axyridis* were higher than found in other species of coccinellid. These results were reflected the suitability of fresh and frozen GME

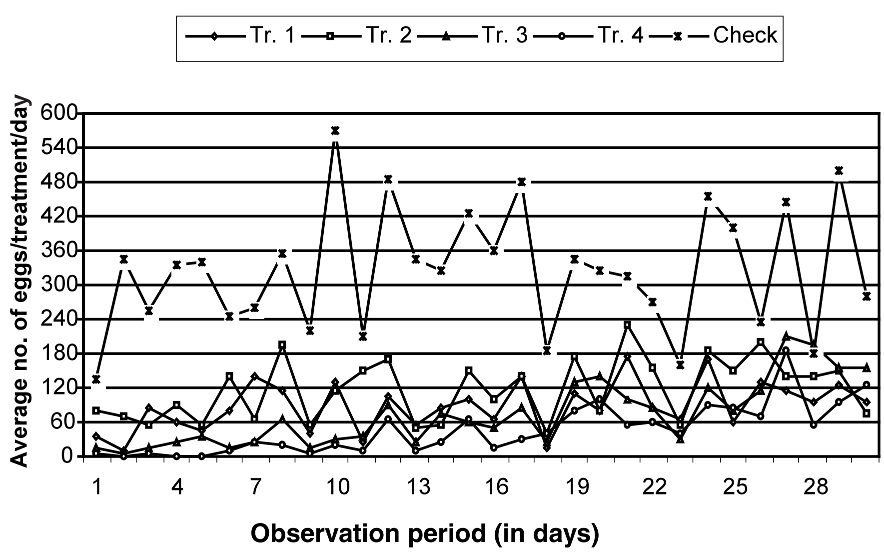

Fig. 2. *Daily rate of oviposition per treatment during the 30-day observation period under crowding condition and check*

Table 6. *Values of life table parameters of* H. axyridis *and other coccinellid species reared on different preys*

Coccinelid species	Preys	T	DT	R_o	r_m	e^{rm}	Reference
Stethorus picipes Casey	*Oligonychus punicae*	21.00	–	–	0.122	–	Tanigoshi and McMurtry (1977)
Rodolia iceryae Janson	*Icerya pattersoni* Newstead	61.17	10.83	50.16	0.064	1.067	Kairo and Murphy (1995)
Coccinella septempunctata L.	*Acyrthosiphon pisum* Harris	37.20	–	559.6	0.170	1.200	Phoofolo and Obrycki (1995)
Nephaspis oculatus (Blatchley)	*Bemisia argentifoli* Bellow and Perring	51.27	8.89	54.27	0.078	1.080	Liu et al. (1997)
Coleomegilla maculata DeGeer	*A. pisum*	41.10	–	54.00	0.100	1.100	Phoofolo and Obrycki (1997)
	Ostrinia nubilalis (Hübner) eggs	36.38	–	37.89	0.100	1.110	
Harmonia axyridis	Fresh GME	37.87	4.53	289.11	0.153	1.166	This study
	Frozen GME	45.04	5.72	234.96	0.121	1.128	

for mass rearing of this predator. In addition, this predator had a higher capacity to multiply its population than other coccinelids.

Concerning the effect of crowding on the fecundity of *H. axyridis* females, it can be concluded that the highest fecundity was obtained when adults were reared individually in Petri dishes followed by in the first treatment (10 males and 10 females). This is due to cannibalism of laid eggs by adults (both males and females). Okada and Matsuka (1973) reported that predaceous coccinellids ordinarily are reared individually because of cannibalism. Crowding of predators with their preys causes competition and starvation, which in turn reduces survival and adult fitness. Relatively low levels of crowding may be undesirable due to cannibalism (Waage et al., 1985). Cannibalism was the only significant mortality factor during all developmental stages of *H. axyridis*, and the stage most heavily cannibalized was eggs by adults (McClure, 1987). Cannibalism by larvae and adults is a persistent problem in mass rearing of many coccinellid species (Agarwala and Dixon, 1992). Adult females of *Chilocorus nigritus* Fabricuis have been observed on numerous occasions to oviposit and immediately turn to eat the eggs. Egg cannibalism by both males and females of *C. nigritus* showed that some individuals consumed up to two-thirds of the total laid (Ponsonby and Copland, 1998).

The results of the current study assure that *H. axyridis* can survive, develop and reproduce normally when reared on fresh or frozen GME. It can be concluded that the mass rearing of this coccinellid predator on the factitious prey tested in this study could offer a valid alternative to using normal preys (e.g. aphids, coccids and other soft-bodied insects). The findings of the current study indicate that *H. axyridis* would be a suitable biological control candidate for mass rearing and release in Egyptian fields.

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