Bulletin of Insectology **61** (2): 291-297, 2008
ISSN 1721-8861

Development and demographic parameters of the carob moth *Apomyelois ceratoniae* on four diet regimes

Ali Norouzi, Ali Asghar Talebi, Yaghoub Fathipour
Department of Entomology, College of Agriculture, Tarbiat Modares University, Tehran, Iran

Abstract

The carob moth, *Apomyelois ceratoniae* (Zeller) (Lepidoptera Pyralidae), is a serious pest of pomegranate in Iran and a well known pest of many fruits from a wide range of plant families as well as dried fruits during storage. Development and demographic parameters of *A. ceratoniae* were studied in a growth chamber at temperature of 30 ± 1 °C, relative humidity of 75 ± 5% and a photoperiod of 16:8 (L:D) on fruits of pomegranate, pistachio, fig, and date. The results indicated that mean generation times were 42.38 ± 0.47, 45.24 ± 0.42, 57.83 ± 1.19 and, 89.55 ± 1.48 days on pomegranate, pistachio, fig and, date, respectively. The gross fecundity rate on pistachio was higher than those on three other diets. The net reproductive rate (R_o) was calculated to be lowest on date (3.64 ± 0.59) and highest on pistachio (45.74 ± 4.17). The net reproductive rates on four diets differed significantly. The highest and lowest amounts of the intrinsic rate of increase (r_m) were observed on pomegranate (0.107 ± 0.013) and date (0.018 ± 0.002), respectively. The r_m values were significantly different among four diets. The highest estimated doubling time was 37.46 ± 5.82 days on date. Our findings showed that the reproduction and population growth parameters of the carob moth on fruits of pomegranate and pistachio were higher than those obtained on fig and date.

Key words: *Apomyelois ceratoniae*, diet, life table, reproduction, population parameters.

Introduction

The carob moth, *Apomyelois ceratoniae* (Zeller), also known as date moth, is an important pest attacking fruit trees and nut crops throughout the world (Gothilf, 1984; Warner, 1988). It is a major field pest of pomegranate, *Punica granatum* L. (Al-Izzi *et al*., 1985), pistachio, *Pistacia vera* L. (Dhouibi, 1982; Mehrnejad, 1993), date, *Phoenix dactylifera* L. (Echlin, 1982), almond, *Prunus dulcis* (Mill.) (Gothilf, 1984), but there are a few records of its damage on other host plants such as fig, *Ficus carica* L. (Shakeri, 1993), walnut, *Juglans nigra* L. (Balachowsky, 1975), dried fruits, nuts, as well as other non-economic plants of a wide range of plant families (Doumandji-Mitiche and Doumandji, 1982).

The carob moth is a well-known pest of date (Deglet Noor variety) in Algeria (Lepiger, 1963; Wertheimer, 1958) and Tunisia (Dhouibi, 1982), where it infested dates in field and in storage. Since the "Deglet Noor" variety comprise 85% of the date crop in the Coachella Valley (USA) (Nixon and Carpenter, 1978), control of this pest is economically important to date growers. The carob moth poses a serious economic threat to the date industry. During the past 25 years, the carob moth caused from 10-40% damage in the harvestable crop annually (Nay *et al*., 2006; Warner, 1988). The date fruits do not become infested until they begin to ripen (Lepiger, 1963; Wertheimer, 1958). The larvae then enter the date by crawling beneath the calyx. There may be some olfactory stimuli that attract the larvae to the calyx (Dhouibi, 1982).

In Iran up to 60412 hectares of pomegranate orchards have been cultured in recent years (Shakeri, 2004). The high quality of pomegranates in Iran has made it an important export commodity. The most important pest on pomegranate fruits is carob moth, *A. ceratoniae*. Its larvae feed inside the fruit and highly affects fruit quality, making the fruit unmarketable and unfit for human consumption (Shakeri, 2004). Adult carob moths begin to emerge from early May in Iran, preferably attacks pomegranate first. Apparently, pomegranate fruits provide suitable conditions for oviposition of the carob moths. This may be because of the physical condition of pomegranate neck that protects the eggs and leads larvae to the inside of the fruit. After completing some generations on pomegranate, as soon as other host plants provide suitable conditions for laying eggs such as the grooves and tracks that occur on pistachio (Mehrnejad, 1992), some individuals may attack those host plants in addition to pomegranate. In many parts of pistachio growing area in Iran, up to 10% of pistachio nuts infested by carob moth at harvesting time annually. This insect is able to continue its damage when the nuts are stored under storage conditions. Its maximum activity found to be during September and November in Rafsanjan, the central part of Iran. Adult moths cannot attack to un-cracked hull nuts, however the larvae can penetrate into un-cracked shell from stem end. It appears that the carob moth spend several generations on alternate hosts, mainly pomegranate before pistachio nuts cracking of hulls (Mehrnejad, 1993).

The carob moth is commonly found in pomegranate orchards in Iran, but there are only a few records of its damage on other host plants such as fig (Shakeri, 1993). In Iran, this pest controlled by collecting and burning infected pomegranate fruits at the end of growing season that reduces overwintering sites (Behdad, 1991). However, infected pomegranates may not be the only sites for overwintering of *A. ceratoniae* and collecting them may not effectively prevent overwintering (Mozaffarian *et al.,* 2007).

This control method has also been used for controlling the pest on other fruit such as date (Warner *et al*., 1990). Although, damage of this pest on some hosts especially fig does not cause economic damage but infested figs seem to provide suitable places for overwintering of the pest. In fact, numerous host plants cause that we fail to control of damage on pomegranate (Shakeri, 2004). In spite of the more extensive activity of the carob moth on pomegranate in Iran, some host plants such as fig, pistachio and walnut can provide for increased stored nutritional reserves by larvae that may result in more successful overwintering and higher fecundity in adults. Populations on other host plants can have an important effect on expanding pest population sizes in following years which should be considered in control methods (Mozaffarian *et al*., 2007).

Because of the economic importance of the carob moth, there have been considerable researches on various aspects of the moth's developmental biology, as well as some basic measures of fitness on various field hosts and artificial diets. These studies determined the number of generation per year (Al-Izzi *et al*., 1985; 1987; Gothilf, 1970; 1984; Warner, 1988), developmental rate of the egg, larval, and pupal stages (Al-Izzi and Al-Maliky, 1996; Al-Izzi *et al*., 1988; Al-Rubeai, 1987; Cox, 1976; 1979; Gothilf, 1968; 1969; 1970; 1984; Moawad, 1979; Navarro *et al*., 1986; Warner, 1988), effect of host moisture content on development (Cox, 1976; Gothilf, 1968; 1969; Navarro *et al*., 1986; Nay, 2006; Warner, 1988), light regimes (Cox, 1979; Warner, 1988) and demographic parameters on date (Nay, 2006). Mehrnejad (1992) determined some biological characters of *A. ceratoniae* such as adult emergence, sort of larvae damage, degree of infection, overwintering and winter mortality under natural condition in pistachio orchards.

The effects of protein substrate (wheat, soybean, and corn meal), sugar substrate (honey and date syrup), and sugar percentage (6.12 and 24%) on different biological aspects such as larval period, pupal period, pupal weight, adult weight, mortality, fecundity, fertility, egg hatching percentage and adult longevity were studied by Fakharzadeh (2002). The effects of three artificial diets on size of different stages of carob moth were studied by Ghavami (2006).

A little data are available on demographic parameters of *A. ceratoniae* in Iran and over the world. Therefore, the objective of the present study was to evaluate the effect of four diets (pomegranate, pistachio, fig, and date) on demographic parameters of the carob moth. The pest population prediction system and management strategies depend on a broad understanding of the pest biology and population parameters. Knowledge of this subject may provide a better view in the pest control.

Materials and methods

Rearing methods

Approximately 800 infested pomegranate fruits by carob moth larvae were originally collected from orchards in the Hasanabad valley, located 50 km south of Ghom, Iran, in November 2006. Fruits were transferred to a growth chamber at temperature of 30 ± 1 °C, relative humidity (RH) of 70 ± 5% and a photoperiod of 16:8 (L:D). Adults emerged from infested fruits were caught by an aspirator and transferred to the mating cages (50 × 50 × 100 cm) for one night. During the mating period, adult moths were provided with 10% honey water solution for feeding. Male and female moths were mated in first night and then each mated female was released separately into a plastic container (volume of 2 l). To facilitate ventilation, a 5 cm diameter opening was cut on top of the plastic container and covered with nylon mesh. During the reproduction period a cotton wool, which was soaked with 10% honey water solution, was placed in container for moths feeding. The newly laid eggs were transferred on four different diets (pomegranate, Malas cultivar; pistachio, Akbari cultivar; fig, Zard cultivar and date, Zahedi cultivar) with a fine hair brush. In each diet, the sex ratio of adults emerged from the larvae reared on particular diet was assessed. The carob moths were reared on each diet in the laboratory for three generations before they were used in the experiments.

Developmental time and life table

To determine the life table parameters, 100 - 130 newly (one day old) eggs of the carob moth were separately placed in Petri dishes (3 cm in diameter) on various diets (pomegranate, pistachio, fig, and date). For easy observation of the first and second instar larvae, pistachio, fig, and date fruits were cut into pieces (about 2 × 3 mm), and pomegranate fruits were cut into single seeds. Seven pieces of each diet were placed in each Petri dish. The pieces of diets were replaced with fresh ones every 2 days throughout the duration of larval development. Developmental stages were checked daily with a stereomicroscope and developmental periods and mortality of eggs, larvae, pupae and adults were recorded. The larval instars were recognized by moulting. This experiment was continued until the death of all individual members of the cohort. Two important life table parameters (survivorship and life expectancy) were calculated by the following formula:

$$l_x = \frac{N_x}{N_o}$$

$$e_x = \frac{T_x}{l_x}$$

where x is unite of age, l_x is age-specific survival rate or the fraction of individuals of the initial cohort alive at age x, N_x is number alive at age x, N_o is starting number of individuals in the cohort, e_x is life expectancy at age x, T_x is the number of time units lived by the cohort from age x until all individuals die: $T_x = \sum L_x$, where L_x is the fraction of individuals alive during the interval between x and $x + 1$.

Reproduction and population growth parameters

In order to calculate demographic parameters of carob moths, 22, 22, 19, and 17 newly emerged (less than 24 h old) females and the same number of males were randomly selected from those were reared on pomegranate, pistachio, fig, and date, respectively, and used to establish single-pair cultures. Each pair was placed into a plastic container (2 l volume), and placed in a growth chamber at temperature of 30 ± 1 ºC, 75 ± 2% RH, and a photoperiod of 16:8 (L:D). The number of eggs laid by each female was recorded daily until the last female died. Eggs after counting were removed. The factors that are essential for calculating of population parameters included: The age of females in days (*x*), the number of females alive at age *x* (*lx*), and the mean number of eggs laid per female alive per day (*mx*).

Data analysis

Standard demographic parameters were calculated from daily records of mortality, fecundity and fertility of cohorts of *A. ceratoniae* females. The reproduction (gross fecundity and fertility rates, net fecundity and fertility rates, mean number of eggs and fertile eggs per female per day) and population parameters [intrinsic rate of increase (r_m), net reproductive rate (R_o), mean generation time (T_c), finite rate of increase (λ) and doubling time (D_T)] were calculated using formulae suggested by Carey (1993).

The statistical differences in demographic parameters were tested using jackknife procedure to estimate the variance for demographic parameters (Meyer *et al.*, 1986). This procedure is used mostly to estimate variance and bias of estimators. It is based on repeated recalculation of the required estimator, missing out each sample in turn (Maia *et al.*, 2000). It is used to quantify uncertainty associated with parameter estimates, as an alternative to analytical procedures, in cases for which the last ones require very complicated mathematical derivation (Maia *et al.*, 2000).

Algorithms for jackknife estimation of the means and variances are described only for r_m . Similar procedures were used for the other parameters. The steps for the application of the method are the following (Maia *et al.*, 2000):

a. Estimation of r_m, considering the survival and reproduction data for all the *n* females, referred to as true calculation. At this point, called step zero, estimates obtained are denoted as $r_{m\,(\mathrm{all})}$.
b. Repeat the procedure described in part *a* for *n* times, each time excluding a different female. In so doing, in each step *i*, data of *n*−1 females are taken to estimate parameters for each step, now named $r_{m\,(i)}$.
c. In each step *i*, pseudo-values are calculated for each parameter, subtracting the estimate in step zero from the estimate in step *i*, For instance, the pseudo-values of r_m, $r_{m\,(j)}$, was calculated for the *n* samples using the following equations:

$$r_{m(j)} = n \times r_{all} - (n-1) \times r_{m(i)}$$

$$r_{m(mean)} = \frac{\sum_{1}^{n} r_{m(j)}}{n}$$

$$VARr_{m(mean)} = \frac{\sum_{1}^{n} (r_{m(j)} - r_{m(all)})^2}{n-1}$$

$$SEMr_{m(mean)} = \sqrt{\frac{VAR(r_{m(mean)}}{n}}$$

The differences in development, reproduction and population parameters were compared using one-way analysis of variance (ANOVA). If significant differences were detected, multiple comparisons were made using the Student-Newman-Keuls (SNK) at $P<0.05$. Statistical analysis was carried out using Minitab software (MINITAB, 2000).

Results

Developmental time and life table

Developmental times of various stages of *A. ceratoniae* on different diets are presented in table 1. The larval period ($df = 3, 161$; $F = 487.949$, $P < 0.05$) and life cycle ($df = 3, 161$; $F = 428.514$, $P < 0.001$) of carob moth on four diets were significantly different. Conversely, no significant differences were observed be-

Table 1. Developmental time (day) of the carob moth *A. ceratoniae* on four diets regimes.

Parameter	Diets			
	Pomegranate	Pistachio	Fig	Date
Incubation period	3.00 ± 0 a	3.06 ± 0.04 a	3.06 ± 0.04 a	3.05 ± 0.049 a
1st instar larvae	3.36 ± 0.07 c	6.11 ± 0.07 b	4.46 ± 0.15 c	7.40 ± 0.46 a
2nd instar larvae	3.24 ± 0.06 c	4.53 ± 0.12 b	3.59 ± 0.10 c	5.5 ± 0.37 a
3rd instar larvae	4.08 ± 0.13 c	4.66 ± 0.07 b	4.42 ± 0.13 bc	5.4 ± 0.23 a
4th instar larvae	5.28 ± 0.19 c	5.37 ± 0.07 c	6.06 ± 0.02 b	9.9 ± 0.36 a
5th instar larvae	8.92 ± 0.41 b	8.26 ± 0.16 b	8.34 ± 0.30 b	13.2 ± 0.37 a
6th instar larvae	ND	ND	11.58 ± 0.10 b	15.5 ± 0.55 a
7th instar larvae	ND	ND	11.91 ± 1.03 b	16.00 ± 0.5 a
Larval development time	24.88 ± 0.44 d	28.95 ± 0.32 c	41.27 ± 1.13 b	72.9 ± 1.194 a
Pupal period	7.08 ± 0.06 a	7.06 ± 0.038 a	7.20 ± 0.12 a	7.23 ± 0.091 a
Preimaginal development time	34.96 ± 0.43 d	39.08 ± 0.31 c	51.59 ± 1.12 b	83.6 ± 1.23 a
Adult longevity	7.42 ± 0.38 a	6.15 ± 0.29 a	6.23 ± 0.4 a	5.95 ± 0.43 a
Life cycle	42.38 ± 0.47 d	45.24 ± 0.42 c	57.83 ± 1.19 b	89.55 ± 1.48 a

Different letters in the rows indicate significant ($P < 0.05$) differences within various diets.

tween incubation period of eggs (df =3, 161; F = 1.049, P = 0.372), pupal period (df = 3, 161; F = 1.699, P = 0.17) and adult longevity (df = 3, 161; F = 3.242, P = 0.054) on various diets. The carob moth larvae were reared on pomegranate and pistachio pupated after five instars, while those were reared on fig and date pupated after 6-7 and 7 instars, respectively. Preimaginal mortality was highest on date (65%) followed by fig (41%) and it was very lower on pomegranate and pistachio (table 1). The life expectancy (e_x) of one-day-old larvae was estimated to be 37.90, 38.81, 36.37, and 20.52 days, and the life expectancy values at the beginning of adult emergence were 13.27, 10.38, 12.34, and 14.17 days on pomegranate, pistachio, fig, and date, respectively (figure 1).

Reproductive and population growth parameters

The gross fecundity rate (i.e. the mean number of eggs per female per generation) varied from 48.20 on date to 180.39 on pistachio (table 2). The gross fecundity rates were significantly affected by various diets (df = 3, 79; F = 30.376, P < 0.05). The highest amounts of gross fertility rate were observed on pistachio (108.75) followed by pomegranate (103.15) (table 2). The gross fertility rates of carob moth were significantly affected on various diets (df = 3, 79; F = 19.361, P < 0.05). The highest and lowest net fecundity rates were also observed on pistachio and date, respectively (table 2). There was significant difference between net fecundity rates on the four diets (df = 3, 79; F = 40.592, P < 0.05). The highest and lowest net fertility rates of carob moth were 91.35 and 7.19 on pomegranate and date, respectively. The net fertility rates were significantly different depending on the diet (df = 3, 79; F = 36.02, P < 0.05). The mean number of eggs per female per day indicated significant differences among pistachio and other diets (df = 3, 79; F = 45.389, P < 0.05). This parameter was highest on pistachio (20.27) and lowest on date (4.38) (table 2). Also the number of hatched eggs laid per female per day indicated similar effects of the diet (df = 3, 79; F = 25.46, P < 0.05).

The population growth parameters of *A. ceratoniae* on four diets are shown in table 3. There were significant differences between the net reproductive rates (R_o) on different diets (df = 3, 79; F = 42.20, P < 0.05). The highest amount of R_o was obtained on pistachio (45.74) and the lowest value was observed for date (3.64). The r_m values of carob moth on four diets differed significantly (df = 3, 79; F = 225.91, P < 0.05), however this parameter on pomegranate and pistachio was not significantly different. The highest amount of r_m was observed on pomegranate (0.107) and the lowest on date (0.018). There were significant differences between the λ-value on different diets (df = 3, 79; F = 220.520, P < 0.05). The highest λ-values were observed on pomegranate (1.114) and pistachio (1.112) (no significant difference)

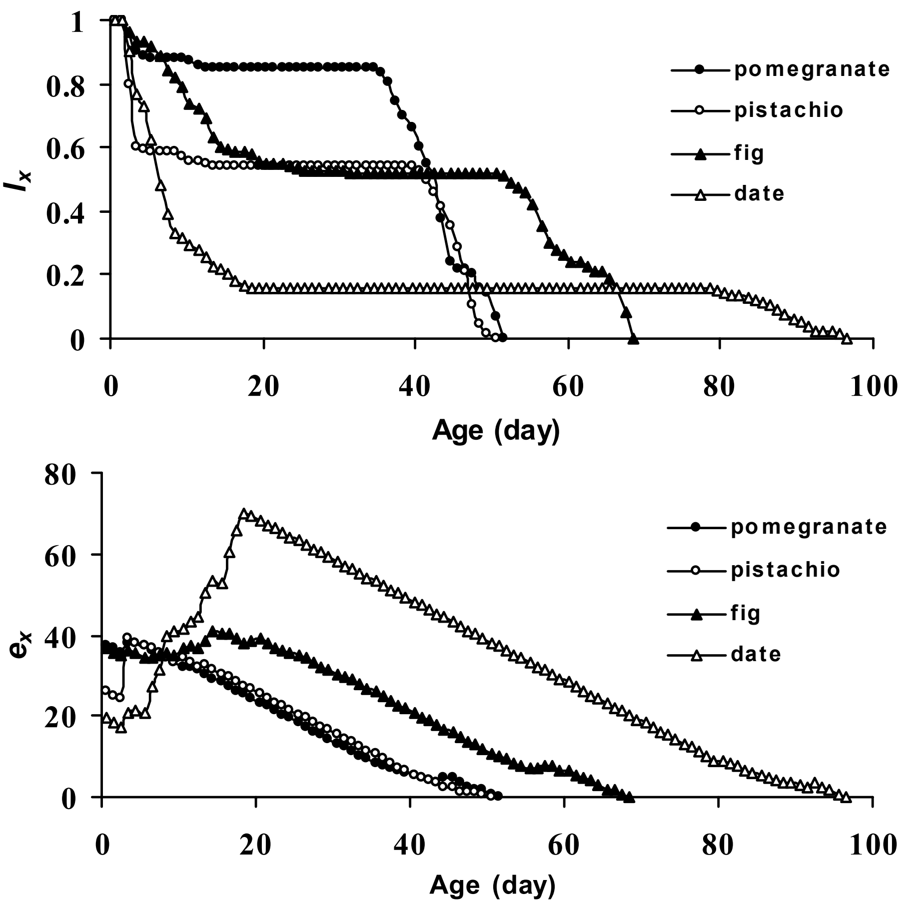

Figure 1. Age-specific survivorship (l_x), and life expectancy (e_x) of the carob moth *A. ceratoniae* on four diet regimes.

Table 2. The reproductive parameters of the carob moth *A. ceratoniae* on four diet regimes.

Parameter	Diets			
	Pomegranate	Pistachio	Fig	Date
Gross fecundity rate	113.35 ± 7.4 b	180.39 ± 16.6 a	55.78 ± 7.89 c	48.20 ± 7.79 c
Gross fertility rate	103.15 ± 6.74 a	108.57 ± 9.93 a	51.88 ± 4.34 b	39.04 ± 6.31 b
Net fecundity rate	75.07 ± 6.54 a	91.35 ± 8.29 a	26.37 ± 4.05 b	7.19 ± 1.18 c
Net fertility rate	68.31 ± 5.96 a	54.81 ± 4.98 b	24.52 ± 3.76 c	5.82 ± 0.96 d
Mean egg per day	5.64 ± 0.37 b	20.11 ± 1.80 a	5.58 ± 0.77 b	4.38 ± 0.71 b
Mean fertile egg per day	5.13 ± 0.33 b	12.06 ± 1.10 a	5.19 ± 0.73 b	3.55 ± 0.57 b

Different letters in the rows indicate significant ($P < 0.05$) differences within various diets.

and the lowest on date (1.018). The highest doubling time (D_T) was observed on date (37.46 days) and there were significant differences between D_T of carob moth on date with other diets ($df = 3, 79$; $F = 31.38$, $P < 0.05$). The highest and lowest generation time (T_c) of *A. ceratoniae* were observed on date (72.13 days) and pomegranate (34.00 days). The generation time (T_c) of *A. ceratoniae* significantly differed among individuals fed with four diets ($df = 3, 79$; $F = 827.39$, $P < 0.05$).

Discussion and conclusions

Although carob moth is an important pest of date fruits in some countries such as Tunisia, Morocco, Algeria, Libya, Iraq, Saudi Arabia and Israel (Vreysen *et al*., 2006) and some parts of Central America (Warner, 1988) but there is no report of carob moth damage on date in Iran. It may be possible the isolated populations of carob moth, that occupy different geographic areas, are genetically different. In Tunisia, the carob moth causes economic losses with infestation rates as high as 90% in pomegranates, especially in the south of the country, 75% in pistachio, and 20% in date. The government has established a maximum infestation level of 5% for date destined for the export market (Vreysen *et al*., 2006). The developmental times of carob moth reported here, partially agree with Yousefi *et al*. (2002), Mehrnejad (1992) and Nay (2006). The results of the present study showed the evident effects of various diets on the developmental time, survival and fecundity of *A. ceratoniae*. No other study has compared the demographic parameters of *A. ceratoniae* on pomegranate, pistachio and fig. While, some aspects of biological characteristics of *A. ceratoniae* have been studied on maize artificial diet and almond (Ghavami, 2006; Hung *et al*., 2003; Navarro *et al*., 1986), pistachio (Mehrnejad, 1992), date (Nay, 2006), and pomegranate (Yousefi *et al*., 2002). The percent study suggests that the larval instar number of *A. ceratoniae* is affected by food quality, a pattern described in several other Lepidoptera. Kingsolver (2007) showed that *Manduca sexta* L. (Lepidoptera Sphingidae) from a field population in North Carolina (USA) shows substantial intraspecific variation in the number of larval instars when feeding on a modified artificial diet. Individuals with six instars consistently exhibited slower growth rates during early larval development than individuals with five instars. Twine (1978) stated that the number of larval instars of *Helicoverpa armigera* (Hübner) (Lepidoptera Noctuidae) varied from five to seven when larvae were reared at a constant temperature on an artificial diet.

Our results clearly showed that the life cycle of carob moths reared on pomegranate was longer (42.38 days) than the data reported by Yousefi *et al*. (2002) on pomegranate (35.00 days at 30 ºC). The larval period of carob moth obtained in our investigation on pomegranate (24.88 days) was higher than that reported by Ghavami (2006) (17.93 days at 27 ºC). This difference could be attributed to difference in temperature. We found no significant difference in incubation period (ranged from 3.00 to 3.05 days) between four diets. Our findings are similar to those reported by Mehrnejad (1992) (2.71 days on pistachio at 30 ºC) and Al-Rubeai (1987) (3.6 days on artificial diet at 27 ºC). In the present study, the pupal period of *A. ceratoniae* on various diets was similar to that found by Mehrnejad (1992) for carob moth on pistachio (7.18 days at 30 ºC). No significant difference was observed between the adult longevity of *A. ceratoniae* reared on four diets. The carob moth larvae that were reared on pomegranate and pistachio passed through fewer instars larvae than those reared on fig and date. In fact, pomegranate and pistachio seem to provide nutritional requirements of the larvae better than other diets. In our experiments, the larval mortality reared on date fruits was higher in comparison with other diets. This may be result of fruit moisture content of various diets. In our experiments, a commercial dry date (Zahedi cultivar) was used. According to Nay (2006), the mortality rate and developmental time of carob moth can affect by moisture content of date fruits. His studies indicated that only one of 61 carob moths completed larval development within 85 days on date fruits having less than 5.0% moisture content and no larvae survived at moisture content below 3.5%.

In the present study, the highest gross fecundity rate was observed on pistachio but because of low hatching rate rather than other diets, gross fertility rate on pistachio decrease more than pomegranate, fig, and date (table 2). The same reason is valid for decrease of net fertility rate in comparison with net fecundity rate on pistachio. The mean number of eggs and the mean number of fertile eggs per female per day were highest on pistachio among various diets. It seems that pistachio has some nutritive compounds that increase females' fecundity (table 2). The intrinsic rate of natural increase (r_m) and net reproductive rate (R_o) were highest on pomegranate and pistachio (table 3), indicating that these two

Table 3. The population growth parameters of the carob moth *A. ceratoniae* on four diet regimes.

Parameter	Diets			
	Pomegranate	Pistachio	Fig	Date
Net reproductive rate (R_o)	38.49 ± 3.13 a	45.74 ± 4.17 a	13.45 ± 2.02 b	3.64 ± 0.59 c
Intrinsic rate of increase (r_m)	0.107 ± 0.013 a	0.100 ± 0.003 a	0.055 ± 0.003 b	0.018 ± 0.002 c
Finite rate of increase (λ)	1.11 ± 0.003 a	1.11 ± 0.003 a	1.06 ± 0.003 b	1.018 ± 0.002 c
Doubling time (D_T)	6.445 ± 0.17 b	6.89 ± 0.17 b	12.62 ± 0.77 b	37.46 ± 5.82 a
Mean generation time (T)	34.00 ± 0.23 d	38.06 ± 0.16 c	47.70 ± 0.23 b	72.13 ± 1.26 a

Different letters in the rows indicate significant ($P < 0.05$) differences within various diets.

diets were a similarly suitable food sources for population growth of the carob moth in comparison with other diets. The doubling time ranged from 6.44 days on pomegranate to 37.46 on date. Our finding showed that date was the unsuitable diet for reproduction and population growth of carob moth. Nay (2006) reported that the doubling time (D_T) of carob moth increased from 9.9 days on date at a high moisture content (26.2%) to 210 days on date at a low moisture content (5.0%). He also determined the doubling times (D_T) on artificial diet, Kimri date, Khalal date, and Ripe date were 5.4, 6.3, 6.7, and 7.5 days, respectively. Demographic studies have several applications such as analyzing population stability and structure, estimating extinction probabilities, predicting life history evolution, predicting outbreak in pest species and finding better diet regime for breeding in laboratory condition for study on various aspect of pest (Vargas and Carey, 1998).

Our study showed that carob moth reared on pomegranate has shortest life cycle, greatest net fertility rate and intrinsic rate of increase (r_m) between other diets. The adult moths emerge from early May in Iran and preferably attacks pomegranate first. Apparently, this fruit provides suitable conditions for oviposition. This may be because of the physical condition of pomegranate neck that protects the eggs and leads larvae to the inside of the fruit. After completing some generations on pomegranate, as soon as other host plants provide suitable conditions for laying eggs, such as grooves and tracks that occur on pistachio (Mehrnejad, 1993; Shakeri, 2004), some individuals may attack those host plants in addition to pomegranate.

In the present study, we described the food-dependent development and demography of an Iranian population of *A. ceratoniae* on four economic important food sources. Life cycle, Net fertility rate, intrinsic rate of increase and some other developmental and demographic parameters were effected in relation to diet regimes. Pomegranate and pistachio diets were provided better condition for development and population growth of carob moth in comparison with fig and date diets. The findings of this study could be used effectively for accurately predicting *A. ceratoniae* population development on different diets. Most recently, we collected two parasitoids, *Habrobracon hebetor* (Say) and *Apanteles laspeyresiellus* Papp (Hymenoptera Braconidae), on larvae of carob moth from central parts of Iran. The later species, which is newly recorded for the fauna of Iran, is probably an effective biological control agent of the carob moth.

Acknowledgements

We are grateful to the Department of Entomology at Tarbiat Modares University (Tehran, Iran) for financial supporting this research. The authors thank to the editor (Prof. Stefano Maini) and three anonymous reviewers for valuable comments and recommendations on the manuscript. We also thank Mr. A. Moosazadeh for his assistance in laboratory experiments.

References

AL-IZZI M. A. J., AL-MALIKY S. K., 1996.- Action of tannic acid on consumption and utilisation of food by *Ectomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae).- *Journal of Stored Products Research*, 32: 195-199.

AL-IZZI M. A. J., AL-MALIKY S. K., YOUNIS M. A., JABBO N. F., 1985.- Bionomics of *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) on pomegranates in Iraq.- *Environmental Entomology*, 14: 149-153.

AL-IZZI M. A. J., AL-MALIKY S. K., JABBO N. F., 1987.- Culturing the carob moth, *Ectomyelois ceratoniae* (Zeller) (Lepidoptera: Pyralidae) on an artificial diet.- *Journal of Economic Entomology*, 80: 277-280.

AL-IZZI M. A. J., AL-MALIKY S. K., JABBO N. F., 1988.- Effect of supplemental dietary Lysine and soybean flour on growth and fertility of *Ectomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae).- *Journal of Economic Entomology*, 81: 970-972.

AL-RUBEAI H. F., 1987.- Growth and development of *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) under laboratory mass-rearing conditions.- *Journal of Stored Products Research*, 23: 133-135.

BALACHOWSKI A. S., 1972.- *Entomologie appliquée à l'agriculture. Tome II. Lépidoptères*.- Masson et Cie. Editeurs, Paris, France.

BEHDAD E., 1991.- *Pests of fruit crops in Iran*, 2^{nd} edition.- Markaz-e-Nashr-e- Bahman, Tehran, Iran.

CAREY J. R., 1993.- *Applied demography for biologists, with special emphasis on insects*.- Oxford University Press, New York, USA.

COX P. D., 1976.- The influence of temperature and humidity on the life-cycle of *Ectomyelois ceratoniae* (Zeller) (Lepidoptera: Phycitidae).- *Journal of Stored Products Research*, 12: 111-117.

COX P. D., 1979.- The influence of photoperiod on the life-cycle of *Ectomyelois ceratoniae* (Zeller) (Lepidoptera: Pyralidae).- *Journal of Stored Products Research*, 15: 111-115.

DHOUIBI M. H., 1982.- Etude bioecologique d'*Ectomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae) dans les zones preahariennes de la Tunisie.- *These de Docteur Ingenieur*, University Pierre et Marie Curie, Paris, France.

DOUMANDJI-MITICHE B., DOUMANDJI S., 1982.- Les ennemis naturels d'*Ectomyelois ceratoniae* Zeller dans Les palmeries de Biskra.- *Bulletin de Zoologie Agricola*, 4: 1-10.

ECHLIN T. D., 1982.- Carob moth in California: new state record.- *California Department of Food and Agriculture, Memo*, Nov. 26.

FAKHARZADEH A. R., 2002.- Rearing of pomegranate neckworm (*Ectomyelois ceratoniae*) on artificial diet and investigation some stimulus factors on oviposition.- *Master of science thesis*, Tehran University, Iran.

GHAVAMI S., 2006.- Effects of three artificial diets on biological characteristics of the carob moth, *Ectomyelois ceratoniae* (Lep.: Pyralidae).- *Journal of Entomological Society of Iran*, 25 (2): 63-76.

GOTHILF S., 1968.- The biology of the carob moth *Ectomyelois ceratoniae* Zell. in Israel. part 1. Mass culture on artificial diet.- *Israel Journal of Entomology*, 3: 109-118.

GOTHILF S., 1969.- The biology of the carob moth *Ectomyelois ceratoniae* Zell. in Israel. part 2. Effect of food, temperature and humidity on development.- *Israel Journal of Entomology*, 4: 107-116.

GOTHILF S., 1970.- The biology of the carob moth *Ectomyelois ceratoniae* Zell. in Israel. part 3. Phenology on various hosts.- *Israel Journal of Entomology*, 5: 161-170.

GOTHILF S., 1984.- Biology of *Spectrobates ceratoniae* on almonds in Israel.- *Phytoparasitica*, 12: 77-87.

HUNG C. C., CHIANG B. Y., WANG W. L., 2003.- Development and fecundity of the carob moth, *Ecomyelois ceratoniae*, reared on different foods and its eclosion, mating and ovipositing behavior.- *Plant Protection Bulletin Taipei*, 45 (3): 185-197.

KINGSOLVER J. G., 2007.- Variation in growth and instar number in field and laboratory *Manduca sexta*.- *Proceeding of the Royal Society B*, 274: 977-981.

LEPIGER A., 1963.- Essais de lutte sur l'arbre contre la pyrale des dattes (*Myelois ceratoniae* Zeller pyralidae).- *Annales des Epiphyties*, 14 (2): 85-101.

MAIA A. H. N., LUIZ A. J. B., CAMPANHOLA C., 2000.- Statistical influence on associated fertility life table parameters using jacknife technique, computational aspects.- *Journal of Economic Entomology*, 93: 511-518.

MEHRNEJAD M. R., 1992.- An investigation on the carob moth, *Apomyelois ceratoniae* (Zell.), new pest of pistachio nuts in Kerman province.- *Master of science thesis*, Tehran University, Iran.

MEHRNEJAD M. R., 1993.- Biology of the carob moth *Apomyelois ceratoniae* a new pest of pistachio in Rafsanjan.- *Applied Entomology and Phytopathology*, 66 (1-2): 1-12.

MEYER J. S., INGERSOLL C. G., MCDONALD L. L., BOYCE M. S., 1986.- Estimating uncertainly in population growth rates: Jackknife vs. bootstrap techniques.- *Ecology*, 67: 1156-1166.

MINITAB, 2000.- *MINITAB User's Guide*, version 13.1.- MINITAB Ltd, UK.

MOAWAD G. M., 1979.- Ecological studies on the pomegranate fruit moth, *Ectomeylois ceratoniae* Zeller (Lepidoptera: Pyralidae), in Saudi Arabia.- *Indian Journal of Agricultural Sciences*, 49: 739-741.

MOZAFFARIAN F., SARAFRAZI A., NOURI GANBALANI G., 2007.- Host plant associated population variation in the carob moth *Ectomyelois ceratoniae* in Iran: a geometric morphometric analysis suggests a nutritional basis.- *Journal of Insect Science*, 7: 1536-2442.

NAVARRO S., DONAHAYE E., CALDERON M., 1986.- Development of the carob moth, *Spectrobates ceratoniae*, on stored almonds.- *Phytoparasitica*, 14: 177-186.

NAY J. E., 2006.- Biology, ecology, and management of the carob moth, *Ectomyelois ceratoniae* Zell. (Lepidoptera: Pyralidae), a past of dates, *Phoenix dactilifera* L. in Southern California.- *Ph.D. Dissertation*, University of California, USA.

NAY J. E., BOYD E. A., PERRING T. M., 2006.- Reduction of carob moth in 'deglet noor' dates using a bunch cleaning tool.- *Crop Protection*, 25: 758-762.

NIXON R. W., CARPENTER J. B., 1978.- Growing dates in the United States.- *USDA Agricultural Information Bulletin*, 207: 63.

SHAKERI M., 1993.- First report of attack of *Spectrobates ceratoniae* Zell. to figs in Iran.- *Applied Entomology and Phytopathology*, 60: 29.

SHAKERI M., 2004.- A review on investigations on pomegranate neck worm in Iran, pp. 18-30. In: *A proceeding on evaluation of finding and current problems associated with Spectrobates ceratoniae management in pomegranate*.- Ministry of Jihad-e-agriculture, organization of research and education, Yazd agriculture and natural resources research center, Iran.

TWINE P. H., 1978.- Variation in the number of larval instars of *Heliothis armigera* (Hübner) (Lepidoptera: Noctuidae).- *Journal of the Australian Entomological Society*, 17: 289-292.

VARGAS R. I., CAREY J. R., 1989.- Comparison of demographic parameters for wild and laboratory-adapted Mediterranean fruit fly (Diptera: Tephritidae).- *Annals Entomological Society of America*, 82: 55-59.

VREYSEN M. J. B., HENDRICHS J., ENKERLIN W. R., 2006.- The sterile insects technique as a component of sustainable aerawide integrated pest management of selected horticultural insects pests.- *Journal of Fruit and Ornamental Plant Research*, 14 (Suppl. 3): 107-131.

WARNER R. L., 1988.- Contribution to the biology and the management of the carob moth, *Ectomyelois ceratoniae* (Zeller) in 'Deglet Noor' date gardens in the Coachella Valley of California.- *Ph.D. Dissertation*, University of California, Riverside, USA.

WARNER R. L., BARNES M. M., LAIRD E. F., 1990.- Reduction of insect infestation and fungal infection by cultural practice in date gardens.- *Environmental Entomology*, 19: 1618-1623.

WERTHEIMER M., 1958.- Un des principaux parasites du palmier dattier algerien, le Myelois decolor.- *Fruits*, 13 (8): 309-323.

YOUSEFI M., HALALI J., GHANBARI A. A., 2002.- Effect of different temperature on developmental stages of pomegranate neck worm moth *Spectrobates ceratoniae* on laboratory condition, pp. 171-172. In: *Proceedings of the 15th Iranian Plant Protection Congress*, 7-11 September 2002, Razi University of Kernamshah, Iran.

Authors' addresses: Ali Asghar TALEBI (corresponding author, e-mail: talebia@modares.ac.ir), Ali NOROUZI, Yaghoub FATHIPOUR, Department of Entomology, College of Agriculture, Tarbiat Modares University, PO Box: 14115-336, Tehran, Iran.

Received December 9, 2007. Accepted September 15, 2008.