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Two-sex life table analysis of population characteristics of almond moth, *Cadra cautella* (Lepidoptera: Pyralidae) on dry and semi-dry date palm varieties

Aref Marouf[1, 2*], Masood Amir-Maafi[2] and Nouraddin Shayesteh[3]

1. Department of Plant Protection, College of Agriculture, University of Urmia, Urmia 57561-51818, Iran.
2. Agricultural Entomology Research Department, Iranian Research Institute of Plant Protection, Tehran 19395-1454, Iran.
3. Department of Plant Protection, Mahabad Branch, Islamic Azad University, Mahabad, Iran.

Abstract: Life table of almond moth, *Cadra cautella* Walker was studied on four main dry and semi-dry date palm varieties (Deyri, Zahedi, Piarom, and Rabbi) of Iran under laboratory conditions. Data were analyzed based on the age-stage, two-sex life table theory. Duration of total preadult stages was 42.54, 45.79, 51.48 and 50.41 days on Deyri, Zahedi, Piarom, and Rabbi, respectively. The highest fecundity of female almond moth on date palm varieties was 245.29 eggs on Zahedi. The intrinsic rate of increase (r_m) on different varieties of date palm ranged from 0.069 d^{-1} (on Piarom) to 0.105 d^{-1} (on Deyri). The highest net reproductive rate (R_0) was on Deyri (95.81 offspring) and the lowest value was on Rabbi variety (42.37 offspring). Our results showed that the highest r_m, the largest fecundity and the shortest generation time of almond moth were observed on Deyri variety. It was concluded that among date palm varieties, Deyri was the most favorable host plant for almond moth reproduction performance.

Keywords: Biology**,** *Cadra cautella***,** date palm, demography, Iran.

Introduction

Iran is the major producer of date palm, *Phoenix dactylifera* L. (Arecales: Arecaceae) in the world. Due to the damage caused by postharvest pests, however, only 10% of its production is exported. Because the storage period lasts nearly one year, damage caused by stored-product pests is considerable. The almond moth, *Cadra cautella* Walker (Lepidoptera: Pyralidae) is one of the major date palm pests in Iran. The infestation begins in date palm plantations. Damages continue in storehouse through infested dates and can go through multiple generations (Howard *et al*., 2001). Besides date palm, dried fig, raisin, flour, rice and maize are reported as hosts of almond moth in Iran (Shahhosseini and Kamali, 1989). In other countries, grains, cereal products, cocoa, chocolate, spices, nuts, dried fruit, processed foods and peanut are reported as hosts of almond moth (Rees, 2007; Hodges and Farrell, 2004). There is, however, little information on the ecology, especially life table of almond moth on date palm varieties.

Life table is an important tool to study the dynamics of animal populations. Demographic data can be used in: projecting population growth, predicting outbreak in pest species, estimating extinction probabilities and timing pesticide applications (Vargas *et al*., 1997; Amir-Maafi and Chi, 2006). Traditional life tables (Birch, 1948; Leslie, 1945; Leslie, 1948;

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* **Corresponding author**, e-mail: marouf@iripp.ir
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Lewis, 1942), however, deal only with female populations and ignore the variable developmental rates among individuals. Because developmental rates differ often between the sexes and among individuals (Istock, 1981), ignoring the sex of individuals can also result in errors (Chi, 1988). Chi and Liu (1985) and Chi (1988) developed an age-stage, two-sex life table model incorporating variable developmental rates for both sexes. Application of life table in entomological researches has been increased in last decade (Feng *et al*., 2009; Yin *et al*., 2009; Hou and Weng, 2010). The main objective of this study was to compare parameters of the life table of *C. cautella* reared on four main dry and semi-dry date palm varieties of Iran. We also calculated demographic parameters of this pest on these date palms using the age-stage, two-sex life table model. Results of this study will be useful to understanding the mechanism of population build-up of *C. cautella* on commercial varieties of date palm. Also this information will be necessary for the development of IPM program for date palm pests in Iran.

Materials and Methods

Almond moth colony

Infested dry and semi-dry date palm were collected from traditional stores and date palm plantations in Arvand-Kenar county (29º 59' N, 48º 31' E) of Khuzestan province of Iran at mid May, 2009. Collected samples were transferred to Laboratory of Agricultural Entomology Research Department, Iranian Research Institute of Plant Protection, Tehran. Infested date palms were kept in a plexiglas box (20 × 14 × 6 cm) at 29 ± 1 ºC, 60 ± 5% RH and photoperiod of 16: 8 (L: D) h in a constant temperature room. Mass rearing boxes of *C. cautella* were put in plastic bag and then, end of hose which was attached to CO_2 capsule, was put into plastic bags for 30 seconds. The anesthetized adult moths were transferred to plexiglas boxes containing 200 g artificial diet. Ingredients of artificial diet were corn meal (27.6%), whole wheat flour (27.6%), rodent laboratory chow (13.8%), dried yeast (7%), honey (7%), glycerin (7%), wheat germ (3%) and oatmeal (7%) (Sing and More, 1985). The boxes were kept in a constant temperature room as described above. *C. cautella* was reared for one generation on artificial diet.

Life table study

Adult moths emerging from the artificial diet were released into boxes with dry date palm (Zahedi variety) and semi-dry date palm (Deyri, Piarom, and Rabbi varieties) separately and kept in a constant temperature room as described earlier for two generations. These varieties are most important commercial dry and semi dry date palm of Iran. To study the life table, five pairs of *C. cautella* that emerged from the respective date colony were released in mating cylinder. These cylinders were made of plexiglas (5.5 cm in diameter, and 5.5 cm in height) with a hole (1.5 cm in diameter) in the closed end. The hole was covered with a fine mesh net for ventilation. After release of five pairs of *C. cautella* into a cylinder, the bottom end was covered by fine mesh net and was placed in a Petri dish (5.7 cm in diameters). Eggs laid within 24 h were collected by fine brush and used for life table study. Eggs were individually placed on fruit that were longitudinally cut into halves and placed in plastic Petri dishes (6 cm in diameters, and 1 cm in depth,) with a hole in the lid covered with a fine mesh net for ventilation. Eighty eggs were used for each date palm variety. All Petri dishes were kept in the constant temperature room as above. The survival and developmental stage were checked daily. As adult moths emerged, males and females were paired and placed in a new mating cylinder as described above. The daily fecundity was then recorded until the death of all individuals.

Data analysis

The raw data of all individuals were analyzed based on the age-stage, two-sex life table theory (Chi and Liu, 1985; Chi, 1988). The survival rate (s_{xj}), where x is the age and j is the stage, was calculated first. It is the probability that an egg will survive to age x while in j stage. The fecundity (f_{xj}), the age-specific survival rate (l_x), the age-specific fecundity (m_x), and the population parameters (r, the intrinsic rate of increase; λ, the finite rate of increase, $\lambda = e^r$; R_0, the net reproductive rate; T, the mean generation time) were calculated accordingly (Chi, 2012). In this research, the intrinsic rate of increase is calculated by using bisection method (Burden and Faires, 2005) from $\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$ with age indexed from 0 (Goodman, 1982). The mean generation time (T) is defined as the time that a population can increase to R_0-fold of its population size at the stable age distribution. It means $e^{rT} = R_0$ or $\lambda^T = R_0$. The mean generation time is then calculated as $T = (\ln R_0)/r$. The gross reproductive rate (GRR) is calculated as $GRR = \sum m_x$. The bootstrap (Efron and Tibshirani, 1993) technique was used to estimate the means, variances, and standard errors of the population parameters. Because bootstrapping uses random resampling, a small number of replications will generate variable means and standard errors. To generate less variable results, we used 10,000 replications in this study. The bootstrap method is included TWOSEX-MSChart (Huang and Chi, 2012). We used the Tukey-Kramer procedure (Dunnett, 1980) to compare the differences among populations reared on different varieties. Drawings were done using Sigma Plot (2011) software.

Results

The effect of different varieties of dry and semi-dry date palm on developmental time, adult longevity, adult pre-oviposition period (APOP), total pre-oviposition period (TPOP) and fecundity of *C. cautella* are given in Table 1.

No significant difference was observed for egg incubation on all date palm varieties. Developmental time of larvae (F = 12.68, df = 3,173; P < 0.001) and pupae (F = 9.23, df = 3,165; P < 0.001) showed significant differences among the date palm varieties. The larval and pupal developmental times were shortest on Deyri and Rabbi varieties respectively (Table 1). The total developmental time of *C. cautella* was shortest (F = 5.47, df = 3,165; P < 0.002) on Deyri compared with all other date palm varieties. On all date palm varieties, the total developmental time of females was longer than that of males. The shortest male longevity was observed on Deyri variety. Moreover, females longevity on all date palm varieties was longer than that of males (Table 1).

APOP of *C. cautella* on all date palm varieties was less than one day (Table 1). It shows that some females can lay eggs on the onset of emergence. The date palm varieties also showed significant effect on the TPOP of *C. cautella* (F = 4.80, df = 3, 90; P < 0.004) (Table 1).

The mean female fecundity of *C. cautella* showed significant differences among the date palm varieties (F = 7.24, df = 3, 90; P < 0.002). Based on Table 1, mean female fecundity was highest (245.29 ± 16.60 eggs) on Zahedi variety and lowest (147.70 ± 23.04 eggs) on Piarom variety.

Out of 80 eggs used at the beginning of the life table study on each variety, the highest number of adult emergence was observed on Deyri (33 females, 19 males) with a sex ratio 0.63 ♀/adult (Table 2). The preadult mortality was the highest on Rabbi (57.6%) and lowest (35%) on Deyri.

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Table 1 Basic statistics (mean ± SE) of of *Cadra cautella* life history on dry and semi-dry date palm varieties in laboratory condition.

Statistics	Stage or Sex	Deyri	Zahedi	Piarom	Rabbi
Developmental time (d)	Egg	3.10 ± 0.09 a (n=60)	2.98 ± 0.10 a (n = 54)	2.95 ± 0.09 a (n=66)	3.03 ± 0.06 a (n = 61)
	Larvae	32.67 ± 1.40 c (n=52)	36.12 ± 1.95 bc (n = 45)	40.16 ± 1.48 ab (n=42)	41.83 ± 2.00 a (n = 38)
	Pupae	6.33 ± 0.17 b (n=52)	6.65 ± 0.26 b (n = 43)	7.55 ± 0.32 a (n=40)	6.32 ± 0.18 b (n = 34)
Total developmental time (Pre-adult) (d)	Female	42.91 ± 1.81 b (n=33)	50.81 ± 3.79 a (n = 21)	54.04 ± 2.10 a (n=23)	55.53 ± 3.73 a (n = 17)
	Male	41.89 ± 2.10 b (n=19)	41.00 ± 1.34 b (n = 22)	48.00 ± 1.73 a (n=17)	45.29 ± 1.31 ab (n = 17)
	All	42.54 ± 1.37 b (n=52)	45.79 ± 2.09 ab (n = 43)	51.48 ± 1.47 a (n=40)	50.41 ± 2.14 a (n = 34)
Adult longevity (d)	Female	10.42 ± 0.74 a (n = 33)	10.71 ± 0.85 a (n = 21)	12.09 ± 0.77 a (n=23)	10.24 ± 0.96 a (n=17)
	Male	6.05 ± 0.74 b (n = 19)	7.86 ± 0.77 ab (n = 22)	9.00 ± 1.07 a (n=17)	8.00 ± 0.86 ab (n = 17)
APOP (d)	Female	0.52 ± 0.12 a (n = 33)	0.76 ± 0.09 a (n = 21)	0.65 ± 0.17 a (n=23)	0.88 ± 0.15 a (n = 17)
TPOP (d)	Female	43.19 ± 1.83 b (n = 33)	51.57 ± 3.80 a (n = 21)	55.75 ± 2.36 a (n=23)	56.41 ± 3.79 a (n = 17)
Fecundity (eggs/Female)	Female	235.45 ± 19.65 a (n=33)	245.29 ± 16.60 a (n = 21)	147.70 ± 23.04 b (n=23)	198.41 ± 26.69 ab (n = 17)

The means followed by different letters in each row are significantly different ($P < 0.05$, least significant difference).

Table 2 Number of adults emerged, percentage of mortality, sex ratio and development index of *Cadra cautella* on dry and semi-dry date palm varieties in laboratory condition.

Variety	Adults emerged (n)		Pre-adult mortality (%)				Sex ratio	Development index (D. I.)
	Female	Male	Egg	Larvae	Pupae	Total		
Deyri	33	19	25	10	0	35	0.63	1.53
Zahedi	21	22	7.5	36.2	2.5	46.2	0.49	1.17
Piarom	23	17	17.5	30	2.5	50	0.57	0.97
Rabbi	17	17	23.8	28.8	5	57.6	0.50	0.84

Age-stage specific survival rate gives the probability that a newly laid egg will survive to age *x* and stage *j*. The age-stage specific survival rates (s_{xj}) of *C. cautella* on different date palm varieties are shown in Fig. 1. Because of variation in the developmental rate among individuals on date palm varieties, there are obvious stage overlapping,. In our study, the highest age-stage specific survival rate of egg stages and adult female was observed on Zahedi and Deyri variety respectively. The l_x is the probability that a new born egg will survive to age *x*.; thus, the curve l_x (Fig. 2) is a simplified version of s_{xj}. The age specific fecundity (f_{xj}) gives the number of offspring produced by individual of *C. cautella* at age *x* and stage *j* (Fig. 2). Because only females reproduce, there is only a single curve f_{x4} (i. e. female is the fourth life stage). Also the age-specific fecundity (m_x) and the age-specific maternity (l_xm_x) of *C. cautella* are given in Fig. 2. It shows that there is one reproductive peak at the end of reproduction period for females on Deyri and Rabbi varieties, but curves of f_{x4} and m_x do not show this peak at the end of reproduction period for females on Zahedi and Piarom varieties (Fig. 2).

The life expectancy (e_{xj}) of each age-stage group of *C. cautella* on date palm varieties is given in Fig. 3. In the laboratory, life expectancy of *C. cautella* steadily decreases with aging (Fig. 3).

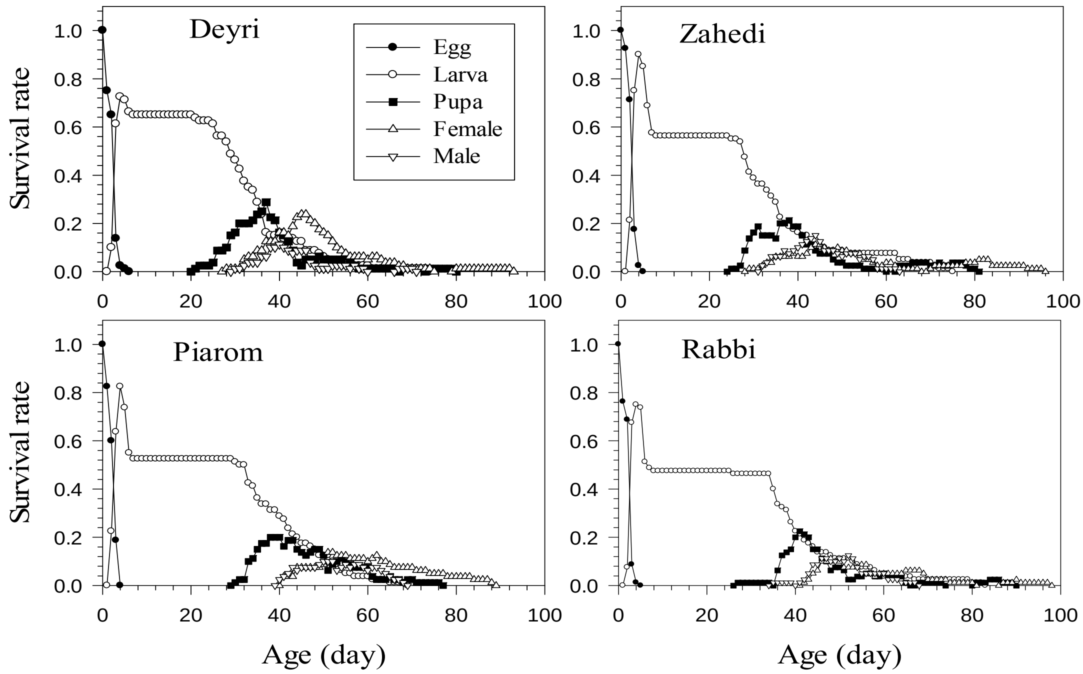

Figure 1 Age-stage specific survival rate of *Cadra cautella* on dry and semi-dry date palm varieties in laboratory condition.

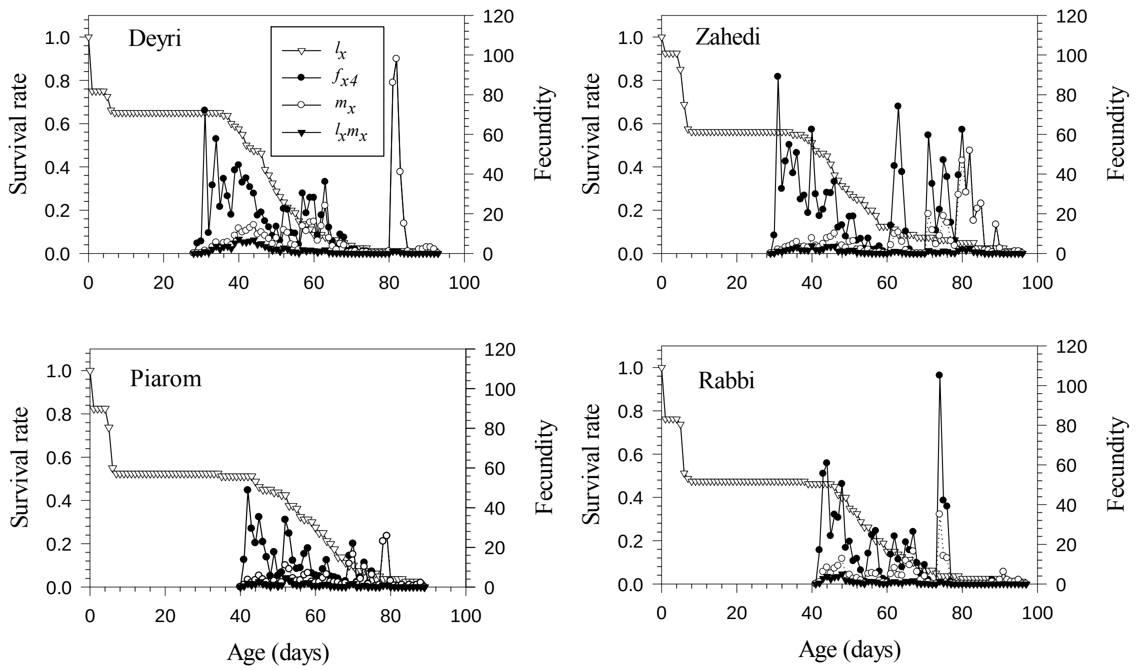

Figure 2 Age-specific survival rate (l_x), female age-specific fecundity (f_{x4}), age-specific fecundity (m_x) and age-specific maternity (l_xm_x) of *Cadra cautella* on dry and semi-dry date palm varieties in laboratory condition.

The intrinsic rate of increase (r_m), the finite rate of increase (λ), the gross reproductive rate (*GRR*), the net reproductive rate (R_0) and the mean generation time (*T*) of *C. cautella* are shown in Table 3. Effect of different varieties of the date palm as larval food on the mentioned parameters was significantly different. The highest intrinsic rate of increase (r_m) and the highest finite rate of increase (λ) of *C. cautella* were observed on Deyri variety (Table 3). Also R_0 (F = 4.37, df = 3, 316; P < 0.005) and *GRR* (F=4.82, df = 3, 316; P < 0.003) value of females from larvae reared on Deyri variety were significantly higher than those of the other varieties. The mean generation time (T) of *C. cautella* was significantly shorter on Deyri and Zahedi varieties (F = 5.84, df = 3, 316; P < 0.001) than that on Rabbi and Piarom (Table 3).

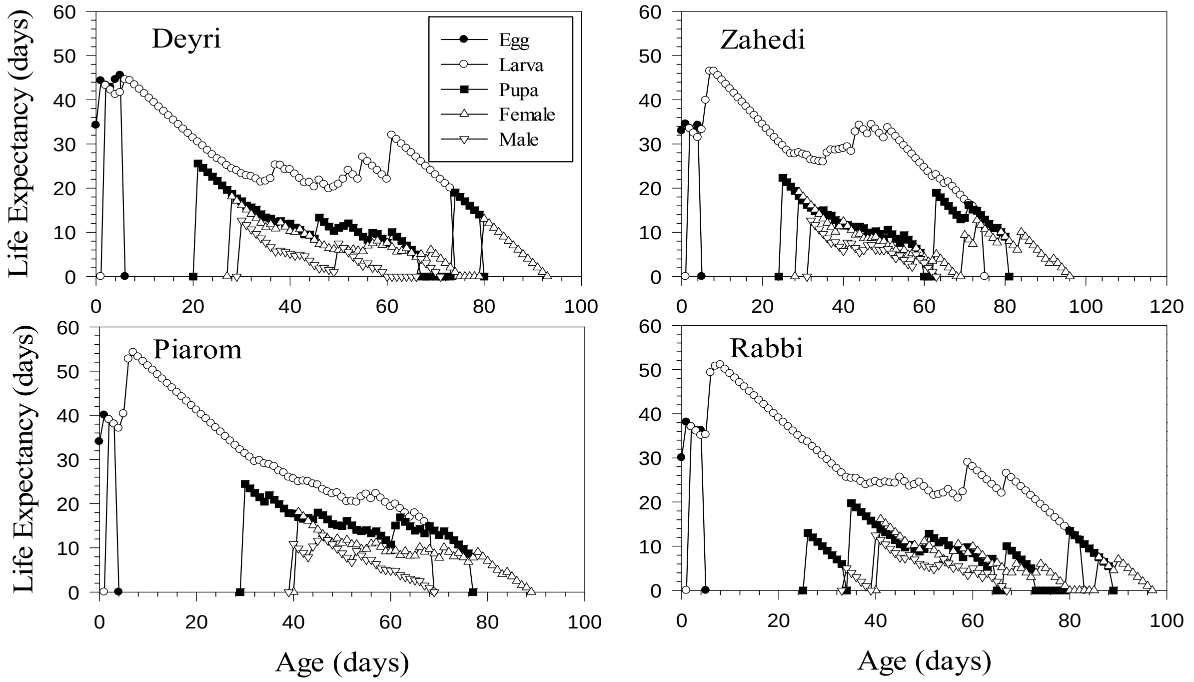

Figure 3 Age-stage life expectancy of *Cadra cautella* on dry and semi-dry date palm varieties in laboratory condition.

Table 3 Intrinsic rate of increase (r_m), finite rate of increase (λ), gross reproductive rate (*GRR*), net reproductive rate (R_0), and mean generation time (*T*) of *Cadra cautella* on dry and semi-dry date palm varieties in laboratory condition.

Population parameters	**Variety**			
	Deyri	**Zahedi**	**Rabbi**	**Piarom**
r (d^{-1})	0.1046 ± 0.0050 a	0.0923 ± 0.0073 a	0.0722 ± 0.0062 b	0.06091.006 b
λ (d^{-1})	1.110 ± 0.0056 a	1.096 ± 0.0080 a	1.074 ± 0.0066 b	1.071 ± 0.0062 b
R_0 (offspring)	95.81 ± 15.34 a	64.60 ± 12.87 ab	42.37 ± 10.73 b	42.73 ± 9.89 b
GRR (offspring)	469.83 ± 114.34 a	459.76 ± 55.95 a	225.98 ± 65.78 b	209.01 ± 35.77 b
T (d)	43.52 ± 1.29 b	45.05 ± 2.53 b	51.51 ± 1.88 a	54.02 ± 2.28 a

The means within a row sharing the same letter are not significantly different at 5% level by using Tukey-Kramer test.

Discussion

In this research, the developmental time of immature stages of female *C. cautella* ranged from 42.91 ± 1.81 on Deyri to 54.04 ± 2.10 days on Piarom variety; while the developmental time of immature stages of male *C. cautella* ranged from 41.00 ± 1.34 on Zahedi to 48.00 ± 1.73 days on Piarom variety (Table 1). Developmental times from egg to adult stage on rolled wheat were 33.9 and 34.2 days for male and female, respectively (Gordon and Stewart, 1986), which were shorter than corresponding periods estimated on date palm. Temperature followed by relative humidity and food sources have been found to be effective factors on developmental time of six species of stored product moths including *C. cautella* (Subramanyam and Hagstrum, 1993). Therefore, differences among the results obtained here with those of others may be due to temperature, relative humidity and food source variations. The life span of adult *C. cautella* on milled maize (without considering the effect of adult sex type) has been reported to be nine days (Siruno and Morallo-Rejesus, 1986), which is similar to results of this study.

The pre-oviposition period was less than one day in all four tested date palm varieties. This indicates that adults were ready to mate and oviposit immediately after emergence. Similar behavior has been observed on female of *Ephestia kuehniella* Zell. (Forouzan, 2003). However, for *Batrachedra amydraula* Meyer (Lep.: Batrachedridae), an important pest of stored date in dry and semi-dry areas, this period has been reported as 3.74 days (Rahmani *et al.*, 2008).

Our results showed that total number of eggs per female ranged from 147.70 on Piarom to 245.29 eggs on Zahedi variety.Morphological and biochemical characteristics of the date palm varieties might have affected the oviposition rates. In Khuzestan province of Iran, there have been positive correlations between *Batrachedra amydraula* Meyric infestation rates and number of date inflorescence, inflorescence weight, fruit weight, length and width of fruit (Latifian *et al.*, 2004). It seems that larval feeding of *C. cautella* on a specific food source for several generations induces their adults to oviposit more on that specific type of food compared to other food sources, indicating adaptation of the adults to larval food source. It is a usual rule that plant species differ greatly in suitability as hosts for specific insects when measured in terms of survival, development and reproductive rates of the pest (Naseri *et al.*, 2009) and it is known that the quality and quantity of nourishment ingested by an insect can affect its survival and reproduction directly (Razmjou *et al.*, 2004). Investigating the effect of food source on fecundity of two strains of *C. cautella* (one strain collected from exported date palms from Iran to USA, and the other strain reared on cereal flour), showed that the first strain oviposited more on date palm compared to moth medium (Mullen and Arbogast, 1977).

The lowest percentage of mortality among egg, larval and pupal stages was observed in the pupal stage. Other reports (Burges and Haskin, 1965; Arbogast, 1981) are in agreement with our results. Our results indicated that Deyri and Zahedi varieties were the most suitable varieties for *C. cautella.* The highest percentage of mortality (35%) of immature stages, the highest (0.63) sex ratio and the highest (1.53) development index (D.I.) on Deyri variety, indicated that *C. cautella* can cause greater damage to Deyri compared with other dry and semi-dry date palm varieties of Iran.

The curves of age-stage specific survival rate (s_{xj}) of *C. cautella* showed the survivorship and stage differentiation as well as the variable developmental rates. For example, the probability that a newborn egg of *C. cautella* will survive to the adult stage is 0.24 for females on Deyri variety. If the raw data were analyzed using a traditional female age-specific life table, it would be impossible to view the changes of the stage structure, because traditional life table ignores male individuals and the variable developmental rate among individuals (Yu *et al.*, 2005). Although the fecundity of C. *cautella* females on Deyri and

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Rabbi varieties had a peak near the end of their reproduction period (f_{x4} and m_x) because of the low survival rate (l_x) at that period (Fig. 2), the contribution of those offspring to the net reproductive rate is negligible. This situation was reported by Amir-Maafi (2000) for *Trissolcus grandis* Thom. (Hym.: Scelionidae), Chi and Su (2006) for *Myzus persicae* (Sulzer) (Hom.: Aphididae) and Rahmani *et al*., (2008) for *B. amydraula* Meyrick.

The life expectancy (e_{xj}) of *C. cautella* on date palm varieties gives an estimation of the time period that individuals of age *x* and stage *j* are expected to live (Gabre *et al*., 2005). The highest (19.09 days) and lowest (16.50 days) life expectancy of new emerged female adults were observed on Zahedi and Piarom varieties, respectively. Rahmani *et al*., (2008) reported that life expectancy of a newly emerged female moth of stored date palm pest (*B. amydraula*) was 13.97 days.

The variability of population validated by the bootstrap technique is shown in Table 3. The intrinsic rate of increase (r_m) is a useful statistic for comparing the population growth potential of different species (Gabre *et al*., 2005). This parameter was developed for studies on insect populations by Birch (1948). However different experimental procedures often lead to difficulties when comparing growth rates of a species from different areas of the world. For example, Hansen *et al*. (2004) reported that *r* for *Sitotroga cerealalla* (Olivier) (Lep.: Gelechidae) reared on maize at 30 °C and 80% RH, was 0.086 d^{-1}. Also Forouzan (2003) found that r_m for *Ephestia kuehniella* Zell. (Lep.: Pyralidae) reared on combined wheat flour and wheat bran at 30 ± 0.5 ºC and 60 ± 5% RH, was 0.068 d^{-1}. The intrinsic rate of increase (r_m) for *Ectomyelois ceratoniae* Zell. (Lep.: Pyralidae) reared on date palm under laboratory conditions was reported to be 0.0928 d^{-1} (Nay, 2006). This study demonstrated differences in demographic characteristics of almond moth on four dried and semi-dried date palm varieties of Iran. These varieties are of high export value and also make up a large portion of the exported dry and semi-dry date palm of Iran. This information is necessary in studies to identify the phytochemicals of date palm varieties that may affect the life table of stored product pests of date palm.

In this study, we observed the highest *r* (0.105 d^{-1}), largest fecundity (95.81 offspring) and shortest generation time (43.52 days) for *C. cautella* on Deyri variety. Among the studied date palm varieties it seems that Deyri variety is preferred by *C. cautella* for feeding to other varieties. These results may provide a better understanding of the ecological parameters of this pest to optimize management strategies for the almond moth.

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ویژگی‌های زیستی جدول زندگی دوجنسی شب‌پره خشکبار روی ارقام خرمای خشک و نیمه‌خشک

عارف معروف[۱و۲]*، مسعود امیرمعافی[۲] و نورالدین شایسته[۳]

۱- گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه ارومیه، ارومیه صندوق پستی ۵۱۸۱۸-۵۷۵۶۱
۲- بخش تحقیقات حشره‌شناسی کشاورزی، مؤسسه تحقیقات گیاه‌پزشکی کشور، تهران صندوق پستی ۱۴۵۴-۱۹۳۹۵
۳- دانشگاه آزاد اسلامی، واحد مهاباد، گروه گیاه‌پزشکی، مهاباد، ایران
* پست الکترونیکی نویسنده مسئول مکاتبه: marouf@iripp.ir
دریافت: ۱۰ آبان ۱۳۹۱؛ پذیرش: ۱۶ اسفند ۱۳۹۱

چکیده: جدول زندگی شب‌پره خشکبار *Cadra cautella* Walker روی چهار رقم مهم خرمای خشک و نیمه‌خشک (دیری، زاهدی، پیارم و ربی) ایران تحت شرایط آزمایشگاهی مورد مطالعه قرار گرفت. داده‌ها براساس فرضیه‌ی جدول زندگی سنی–مرحله رشدی دو جنس مورد تجزیه و تحلیل قرار گرفت. طول دوره‌ی نابالغ روی ارقام دیری، زاهدی، پیارم و ربی به‌ترتیب ۴۲/۵۴، ۴۵/۷۹، ۵۱/۴۸ و ۵۰/۴۱ روز بود. بیشترین میزان باروری حشرات ماده‌ی شب‌پره خشکبار به تعداد ۲۴۵/۲۹ تخم روی رقم زاهدی بود. دامنه‌ی نرخ ذاتی افزایش جمعیت (r_m) روی ارقام مختلف خرما از (روز/۱)۰/۰۶۹ روی رقم پیارم تا (روز/۱) ۰/۱۰۵ روی رقم دیری مشاهده شد. بالاترین و پایین‌ترین نرخ خالص تولید مثل (R_0) به‌ترتیب روی رقم دیری (نتاج ۹۵/۸۱) و رقم ربی (نتاج ۴۲/۳۷) بود. براساس نتایج این پژوهش بالاترین میزان نرخ ذاتی افزایش جمعیت، بیشترین میزان باروری و کوتاه‌ترین طول دوره‌ی یک نسل از شب‌پره خشکبار روی رقم دیری مشاهده شد. در این مقاله مطلوبیت رقم دیری در بین سایر ارقام مورد آزمایش به‌دلیل ارجحیت تولید مثلی شب‌پره خشکبار مورد بحث قرار گرفته است.

واژگان کلیدی: زیست‌شناسی، *Cadra cautella*، خرما، دموگرافی، ایران