Comparative demography and population projection of *Ephestia kuehniella* (Lepidoptera: Pyralidae) and *Callosobruchus maculatus* (Coleoptera: Bruchidae)

Saeideh Mohammadi[1], Nariman Maroufpoor[2], Adil Tonga[3], Ahmet Bayram[3] & Mostafa Maroufpoor[4,*]

1. Department of Plant Protection, Faculty of Agriculture, University of Urmia, Urmia, Iran; 2. Department of Plant Protection, Faculty of Agriculture, University of Tabriz, Tabriz, Iran; 3. Department of Plant Protection, Faculty of Agriculture, Dicle University, Diyarbakir, Turkey & 4. Department of Plant Protection, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran. *Corresponding author, E-mail: m.maroufpoor@uok.ac.ir

Abstract
The Mediterranean flour moth, *Ephestia kuehniella* (Zeller) and the cowpea weevil, *Callosobruchus maculatus* (Fabricius) rank among the most destructive pests in food processing facilities worldwide. *Ephestia kuehniella* and *C. maculatus* may live in the same store simultaneously. To provide a comprehensive ecological based and cost effective control program, the life history and demographic parameters of the both stored product pests were studied at 25 ± 1°C, 60 ± 5% RH, and 16L:8D hours photoperiod. Moreover, population growth potential of the pests compared based on population projection. Life history and demographic parameters of both pests were analyzed using the age-stage, two-sex life table theory. The results revealed that *E. kuehniella* had longer immature developmental time, shorter adult longevity, shorter reproduction period, higher fecundity, higher net reproduction rate, and lower intrinsic rate of increase in comparison with the cowpea weevil. The obtained results have been discussed in terms of developing appropriate management strategies against both pests in the storage.
Key words: flour moth, cowpea weevil, life table, population parameters, stored product pest.

مقایسهٔ پراسنجه‌های جمعیت‌نگاری و پیش‌بینی رشد جمعیت پروانهٔ مدیترانه‌ای آرد *Ephestia kuehniella* (Lepidoptera: Pyralidae) و سوسک چهارنقطه‌ای حبوبات *Callosobruchus maculatus* (Coleoptera: Bruchidae)

سعیده محمدی۱، نریمان معروف‌پور۲، آدیل تونگا۳، احمد بایرام۳ و مصطفی معروف‌پور۴و*

۱– گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه ارومیه، ارومیه، ایران؛ ۲– گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه تبریز، تبریز، ایران؛ ۳– گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه دیسلی، ترکیه و ۴– گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه کردستان، کردستان، ایران.
* مسئول مکاتبات، پست الکترونیکی: m.maroufpoor@uok.ac.ir

چکیده

پروانه مدیترانه‌ای آرد (Zeller) *Ephestia kuehniella* و سوسک چهارنقطه‌ای حبوبات *Callosobruchus maculatus* (Fabricius) از مخرب‌ترین آفات در فرآیند تولید غذا در جهان می‌باشند. پروانه مدیترانه‌ای آرد و سوسک چهارنقطه‌ای حبوبات، ممکن است همزمان در یک انبار وجود داشته باشند. به منظور تهیه یک برنامه کنترلی جامع بوم شناختی و کم‌هزینه، پراسنجه‌های جمعیت نگاری و جدول زندگی این دو آفت انباری در شرایط دمای ۲۵±۱ درجه سلسیوس، رطوبت نسبی ۶۰±۵ درصد و دوره نوری ۱۶ ساعت روشنایی: ۸ ساعت تاریکی مطالعه شد. همچنین توان رشد جمعیت این دو گونه با استفاده از تئوری تغییرات جمعیت مقایسه شد. پراسنجه‌های جمعیت نگاری و جدول زندگی این دو آفت براساس تئوری جدول زندگی سن-مرحله دو جنسی تجزیه شد. نتایج نشان دادند که پروانه مدیترانه‌ای آرد دارای طول دوره نابالغ طولانی‌تر، طول دوره بالغ کوتاه‌تر، دوره زادآوری کوتاه‌تر، باروری بیشتر، نرخ خالص زادآوری بیشتر و نرخ ذاتی افزایش جمعیت کمتر

نسبت به سوسک چهارنقطهای حبوبات است. نتایج به دست آمده، از نظر توسعهٔ راهبردهای مناسب مدیریتی در برابر هر دو آفت در انبار مورد بحث قرار گرفته است.

واژههای کلیدی: پروانه آرد، سوسک حبوبات، جدول زندگی، پراسنجههای جمعیت، آفت انباری.

Introduction

Stored products such as grains, tobacco, and various other dried herbs and spices, as well as many other stored products such as dried fruits and nuts, are attacked by more than 600 species of beetle pests, 70 species of moths and about 355 species of mites (Rajendran & Sriranjini, 2008). The insect pest complex attacking stored food products not only leads to quantity losses but also attenuate their quality. Annual losses in stored grains have been estimated at 10% (90 million tons) worldwide. Two major economically important groups of post-harvest insect pests belong to orders, Coleoptera, and Lepidoptera (Sallam, 2008). Although approximately 70 species of moths have been reported to be associated with the infestation of stored grains and products, only a small number of species are considered as widely distributed and destructive (Cox & Collins, 2002).

Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) is a leading destructive insect in storage throughout the world (Sedlacek *et al*., 1996). It is predominantly found on flour and powdered cereals. The larvae prefer to feed on powdered foods though they can also be on whole grains, beans, and exanimate bodies of insects (Sedlacek *et al.,* 1996). *E. kuehniella* is frequently used in the mass production of many biological control agents (predators and parasites) as well as being a storage pest due to its low cost and easy rearing possibility, non-diapausing life cycle, and high fecundity (Kim & Riedl, 2005; Hamasaki & Matsui, 2006).

The cowpea weevil, *Callosobruchus maculatus* Fabricius (Coleoptera: Chrysomelidae) is a major pest of grain legumes including wheat or any other cultivated cereal crop used as food (Rahman *&* Talukder, 2006). It is a holometabolic insect in which the immature stages feed and develop exclusively inside the seed of legumes (Fabaceae) (Sedaghat *et al.,* 2014). The larvae bore and feed the endosperms making the seed non-viable for germination or sprout production and unsuitable for human consumption. The adults do not feed and utilize their limited lifespan mating and laying eggs on the stored seeds and grains (Devi & Devi, 2014).

Several strategies have been amended to control insects in a storage warehouse or processing plants and more are still being developed (Tiroesele *et al*., 2015). Treatments of synthetic insecticides, especially fumigation, play an important role in stored product pest management (Campolo *et al*., 2018). In addition, improved storage technologies can help for efficient management of insect pests in storage. To minimize the damage caused by insect infestation, the combination of effective and environmentally friendly approaches should be

employed. Understanding the life history and demographic parameters of co-occurring pest insects may ease fitting appropriate pest management strategies. Therefore, the reproductive and population parameters of such pests should be comparatively examined.

The life table of a pest population provides the most comprehensive narrative of its survivorship, development, and reproduction (Carey, 2001). The demographic parameters of storage pests could be used as a promising tool for predicting their population growth potential e.g., the intrinsic rate of natural increase (r), is one of the estimated life table parameters and a widely used predictor for plant genotype resistance to pests and also designing of precise IPM programs (Golizadeh *et al*., 2010; Khanamani *et al*., 2013; Safuraie-Parizi *et al*., 2014; Nikooei *et al*., 2015; Azadi *et al*., 2018).

Two methods are employed to compute demographic parameters: female base (Carey, 1982) and two-sex life table (Chi, 1988). In Carey's method, notwithstanding many discrepancies between male and female insects in biological characteristics such as longevity, survival rate, predation rate, and pesticide susceptibility, male individuals are ignored into consideration and the changeable developmental rate is dissembled (Chi & Liu, 1985). However, the age and stage structure of a two-sex population could be calculated more precisely using the two-sex life table (Chi, 1988) and the actual control efficiency of the whole population including both sexes could also be determined (Chi & Su, 2006). Therefore, the data obtained from the female-only age-specific life table method for studying pest populations are less accurate than the age-stage, two-sex life table method (Yu *et al.,* 2013).

Although *E. kuehniella* and *C. maculatus* are severe pests of stored products through the worldwide, their demography is not studied, completely. Therefore, a comprehensive understanding of their biology and life history traits is required. In order to successful protection of grains in stores, early detection of pests is essential because it will give an indication for on time using of controlling measures and evaluation of their effectiveness. Predicting the growth of a pest population and anticipating its physical and financial damage are critical for making a correct timing schedule for successful using pest management strategies.

Since future pest management systems will be based on a broad knowledge of ecological characteristics of the pests, estimation of the demographic parameters using the age-stage, two-sex life table procedure, can play a critical role for precisely making decision. Therefore, our study aimed to estimate the demographic parameters of *E. kuehniella* and *C. maculatus* and comparison of their fecundity and longevity under laboratory conditions.

Materials and methods

Insect rearing

E. kuehniella

In order to establish a laboratory colony of *E. kuehniella*, original individuals were obtained from the wheat flour factories of Sanandaj, Kurdestan province, Iran; in 2016. The reference population were reared on 95% whole wheat flour (Variety Sardari) and brewer's yeast (5% by weight) at 25±1°C, 60±5% RH and a photoperiod of 16L: 8D h. infested with the pest eggs (for each 100 gr of diet, around 1000 eggs were used) in 1 L glass jars containing 500g wheat flour covered with pieces of muslin cloth fixed by rubber bands (Goncalves *et al*., 2005).

C. maculatus

A large number of the cowpea weevil, *C. maculatus* was initially gathered from stores of Sanandaj, Kurdestan province, Iran. The cultures were maintained on mung bean, *Vigna radiata* (L.) seeds kept in glass jars of 5×3.5 cm size covered with a thin voile cloth at 25 ± 1°C, 60±5% RH and a photoperiod of 16L: 8D hours. The stock colony was reared under gently huddle situation to certify their appropriate development. The colony was kept for two generations before starting experiments under laboratory conditions.

Life table study

Life table studies of both insects were performed under constant laboratory conditions (25 ± 1°C, 60 ± 5% RH, and 16L: 8D h. photoperiod). Tested adults (200 pairs) were moved to whitewash wheat flour and comminuted barn in the same ratio as above to obtain the cohort eggs of the moth. After 48 h, both sexes were detached from the diet handling a 0.83-mm foramen bolter and under a stereomicroscope; the eggs were put and transferred to the experimental units with 50 replicates per treatment. The experimental unit was Petri dishes (9 cm high x 10 cm diameter) containing 50g of rearing medium.

About 200 adults of 1-2 days old *C. maculatus* were released into Petri dishes of 9 cm size including rearing medium and were allowed mating and oviposition. After 24 h, the adults were removed and the seeds bearing only one egg were selected. The life table studies of the cowpea weevil initiated with 50 eggs.

The experimental units of the above mentioned treatments were monitored daily and duration of different life stages, as well as their survivals were recorded until the adult stage. After emergence of adults, females, and males were paired, and reproductive parameters of the females including preoviposition, oviposition, and total preoviposition periods, as well as daily and total fecundity and longevity, were recorded daily. The dead males were replaced with newly emerged ones in the case of necessity. The eggs were counted and removed daily.

Data analysis

The raw data of life history belong to all individuals were analyzed based on the age-stage, two-sex life table (Chi & Liu 1985; Chi 1988). The life table parameters including the age-stage specific survival rate (s_{xj}) (where x = age in days and j = stage), the age-stage-specific fecundity (f_{xj}) (daily number of eggs produced per female of age x and stage j), the age-specific survival rate (l_x), the age-specific fecundity (m_x), the age-stage-specific life

expectancy (e_{jx}), adult preoviposition period (APOP, the preoviposition period counted starting from the adult emergence), total preoviposition period (TPOP, the preoviposition period counted commenced upon birth) and the population growth parameters such as the net reproductive rate (R_0), intrinsic rate of increase (r), finite rate of increase (λ), and mean generation time (T) was calculated accordingly. The age-specific survival rate (l_x) considering both sexes was calculated as follows:

$$l_x = \sum_{j=1}^{k} s_{xj} \tag{1}$$

where k is the number of stages. The age-specific fecundity (m_x) was calculated as follows:

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}} \tag{2}$$

The net reproduction rate is defined as the mean number of offspring that an individual can produce during its lifetime and was calculated as follows:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \tag{3}$$

The intrinsic rate of increase (r) was estimated from the Euler-Lotka formula using the method of iterative bisection with age indexed from 0 to ∞ (Goodman, 1982) as:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \tag{4}$$

The finite rate (λ) was calculated as:

$$\lambda = e^r \tag{5}$$

The mean generation time is the time length that a population needs to increase to R_0-fold of its size when the population reaches the stable age-stage distribution and it was calculated as:

$$T = \frac{\ln R_0}{r} \tag{6}$$

The age-stage specific life expectancy (e_{jx}) is the time that an individual of age x and stage j is expected to live. It was calculated as:

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{m} S'_{iy} \tag{7}$$

The age-stage reproduction value (v_{jx}) represents the contribution of an individual of age *x* and stage *j* to the future population, and it was calculated as follows:

$$v_{jx} = \frac{e^{y(x+1)}}{S_{xj}} \sum_{i=r}^{\infty} e^{-r(i+1)} \sum_{v=i}^{m} S'_{iy} f_{iy}$$

(8)

The standard errors of the developmental times, fecundity, reproduction period and population parameters were estimated by using the bootstrap method (Huang & Chi, 2012; Akköprü *et al.,* 2015), with 100.000 bootstraps to obtain stable estimates of standard errors (Akca *et al*., 2015). The paired bootstrap test was used to compare differences. TWOSEX-MSChart (Chi, 2017a) was employed for the raw data analysis and calculation of population parameters. All routines for both the bootstrap and paired bootstrap tests were included in this program.

Population projection

To project the population growth, we used the method of Chi (1990) and software TIMING (Chi, 2017b). To demonstrate the variability of population growth, we sorted the 100.000 bootstrap results of the finite rate (λ) to find the 2.5[th] and 97.5[th] percentiles, i.e., the 2,500[th] and 97,500[th] sorted bootstrap samples. We then used the bootstrap life table samples that generated the 2.5[th] and 97.5[th] percentiles finite rate (λ) to project the population growth. The results represent the confidence interval of the population growth.

Results

Immature developmental time and adult longevity of both insects are presented in Table 1. There was no significant difference regarding incubation periods of two the pests. However, the larval and pupal developmental times of *E. kuehniella* were significantly longer than *C. maculatus.* The results showed that the duration of the preadult and adult stages of *E. kuehniella* and *C. maculatus* were significantly different and total immature stages of *E. kuehniella* was longer than *C. maculatus* (Table 1)*.* In contrast, the adults of *C. maculatus* lived longer than the adults of *E. kuehniella* and within each examined species, the males lived longer than the females (Table 1).

The results of the measurements of the reproductive parameters clearly showed that both of the species could successfully produce numerous progeny (Table 2). The reproduction parameters revealed that adult preoviposition (APOP) and oviposition period of *C. maculatus* females were significantly longer though the total preoviposition period was significantly lower compared to *E. kuehniella* female. Moreover, the fecundity of *E. kuehniella* females (203.30 eggs) was higher than two folds of *C. maculatus* (95.50 eggs) females (Table 2).

Table 1. Developmental stages (day) of *Ephestia kuehniella* and *Callosobruchus maculatus* (male and female) (Mean ± SE).

Stage	*E. kuehniella* Mean ± SE	*C. maculatus* Mean ± SE
Egg	3.0 ± 0.0a	3.0 ± 0.0a
Larva	32.3 ± 0.3a	17.4 ± 0.1b
Pupa	7.6 ± 0.1a	3.3 ± 0.1b
Female preadult	43.19 ± 0.4a	23.8 ± 0.2b
Male preadult	42.46 ± 0.6a	23.5 ± 0.2b
Female adult longevity	7.6 ± 0.3b	15.5 ± 0.6a
Male adult longevity	8.9 ± 0.4b	16.1 ± 0.7a
Female total longevity	50.8 ± 0.4a	39.2 ± 0.7b
Male total longevity	51.3 ± 0.6a	39.6 ± 0.7b

Standard errors were estimated by using the bootstrap technique with 100,000 resampling. Means followed by same lower case letter indicate no significant difference between the species (paired bootstrap test, *P* < 0.05).

The curves of the age-stage survival rate (s_{xj}) (Fig. 1) represented the survival possibility in various stages along with stage differentiation, which is an important feature of insects. Due to the variation in developmental rates of the individuals, considerable overlaps were recorded. We found that the appearance of adults of *E. kuehniella* occurred later and survived for a shorter time (Fig. 1).
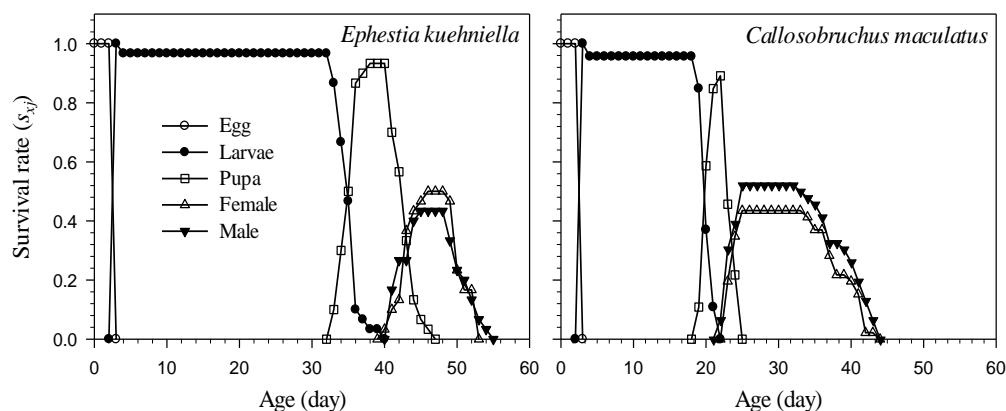
Fig. 1. Age-stage-specific survival rate (s_{xj}) of *Ephestia kuehniella* and *Callosobruchus maculatus*.

Table 2. Adult pre-oviposition period (APOP), oviposition period and total pre-oviposition period (TPOP), fecundity (eggs/female) and oviposition period of *Ephestia kuehniella and Callosobruchus maculatus* (Mean ± SE).

Parameter	*E. kuehniella* Mean ± SE	*C. maculatus* Mean ± SE
APOP (days)	0.30 ± 0.10b	1.50 ± 0.10a
TPOP (days)	43.50 ± 0.50a	23.90 ± 0.20b
Fecundity (egg)	203.30 ± 18.40a	95.50 ± 2.80b
Oviposition days	3.90 ± 0.20b	4.90 ± 0.10a

The standard errors were calculated using the bootstrap procedure with 100.000 bootstraps. The means followed by different letters in the same row are significantly different between both of the species using the paired bootstrap test at 5% probability level.

The age-specific survival rate (l_x) as a function of fecundity (m_x) and net maternity ($l_x m_x$) of the both species revealed that oviposition of *E. kuehniella* began at the age of 39th day with

the highest daily egg production between the 40th and 50th days. Whereas the females of *C. maculatus* commenced oviposition at the day of 23rd and the highest oviposition was recorded at the 25th day. This valence reduced more swiftly in *C. maculatus* than that of the *E. kuehniella* females (Fig. 2).
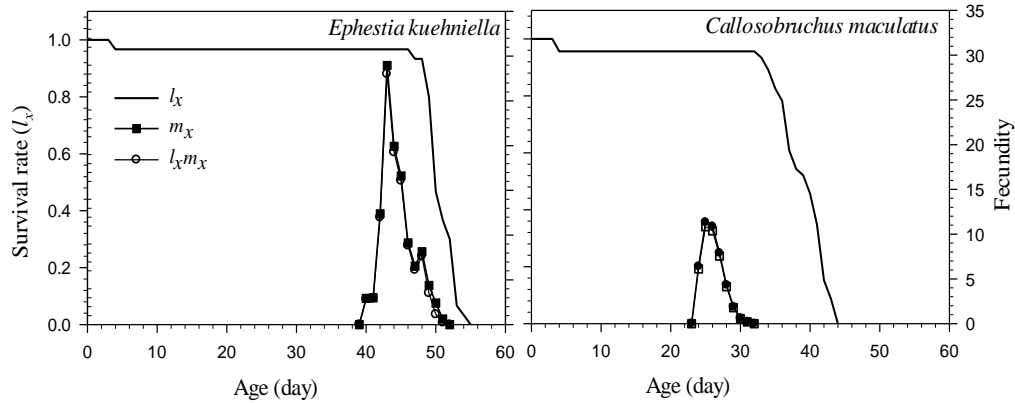

Fig. 2. Age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) of *Ephestia kuehniella and Callosobruchus maculatus.*

The age-stage life expectancy (e_{xj}) of *E. kuehniella* and *C. maculatus* are plotted in Fig. 3. According to the results, the life expectancy of newly laid eggs was higher in *E. kuehniella* (50 days) compared to *C. maculatus* (38 days).
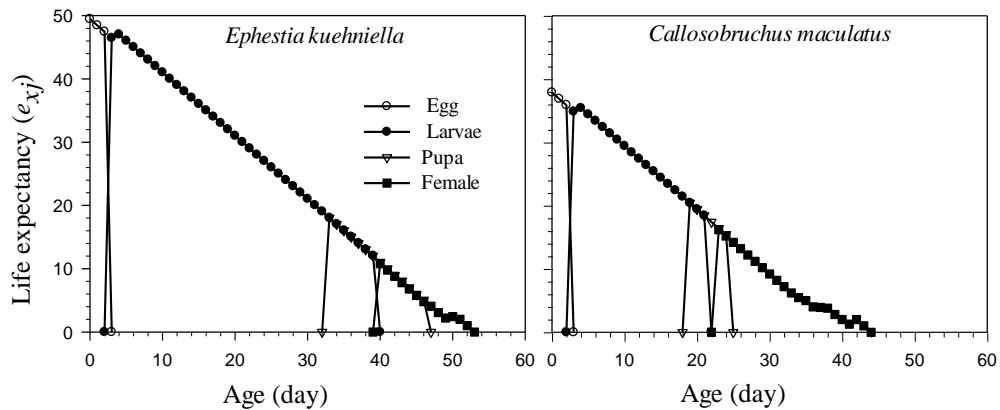

Fig. 3. Age-stage specific life expectancy (e_{xj}) of *Ephestia kuehniella and Callosobruchus maculatus.*

The age-stage reproductive value (v_{xj}) of both species increased significantly after adult emergence. The value of v_{xj} of *E. kuehniella* was the highest (314.39 d^{-1}) on the 40th day when female adults emerged, while in *C. maculatus* the v_{xj} value was peaked at 25th day (95.37 d^{-1}) (Fig. 4).
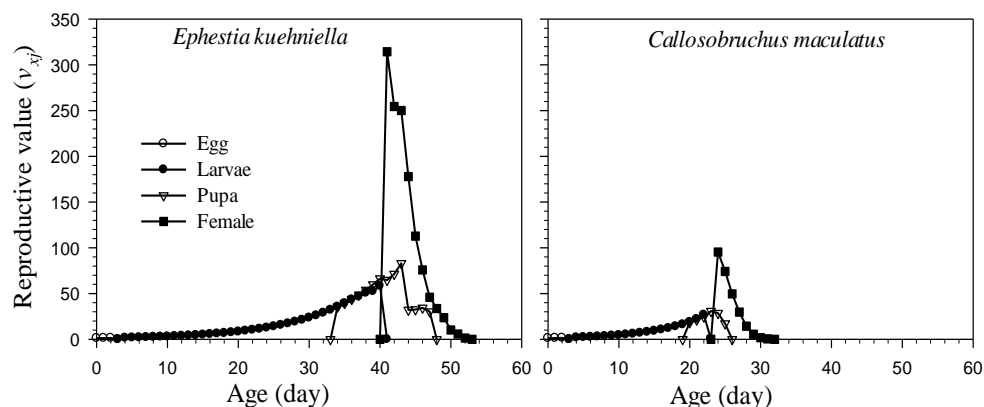
Fig. 4. Age-stage specific reproductive value (v_{xj}) of *Ephestia kuehniella and Callosobruchus maculatus.*

The life table parameters of *E. kuehniella* and *C. maculatus* demonstrated that the intrinsic rate of increase (*r*) and finite rate of increase (*λ*) of *C. maculatus* (0.144 and 1.154 d^{-1}, respectively) were significantly higher than *E. kuehniella* (0.104 and 1.109 d^{-1}, respectively). The net reproductive rate (*R*$_0$) of *E. kuehniella* (108.43 offspring) was higher than that of *C. maculatus* (41.52 offspring). Moreover, the mean generation time (*T*) of *E. kuehniella* was significantly longer (45.10 days) than *C. maculatus* (25.88 days).

Discussion

Comparative demography and population projection of two important stored product pests, *E. kuehniella* and *C. maculatus* were studied under laboratory conditions to enhance our knowledge about their life history.

Under studied conditions, incubation period of both pests, were the same (3 days). While, *E. kuehniella* had longer developmental time than *C. maculatus*. Different from our findings, incubation period of *E. kuehniella* was reported between 3.98- 4.16 days using different host varieties and under different laboratory conditions (28 ± 2°C, 60 ± 5% RH and a photoperiod of 14:10 h / L:D) by Tarlack *et al*. (2015). In the other study, incubation period of *C. maculatus* was reported 2.52 days feeding on cowpea at 30 ± 1°C (Arjanbhai, 2015). The temperature in our study was lower than that of used by Arjanbhai (2015) and Tarlack *et al*. (2015) and resulted shorter incubation period for *E. kuehniella* and longer incubation period for *C. maculatus*. It should be noted that, experimental material of the present study were different than the mentioned works, which may affect incubation period of the studied species.

Total development time including incubation, larval and pupal periods of *E. kuehniella* (42.9 days) was longer than *C. maculatus* (23.7 days). Total development periods of both species were lower than those reported in the previous studies, e.g. Tarlack *et al*. (2015) have

examined development time of *E. kuehniella* on six different wheat varieties and the shortest development time reported on flour of Parsi variety (50.98 days) at temperature $28 \pm 2°C$, $60 \pm 5\%$ RH and 14:10 h / L:D. In another work, the development time of *E. kuehniella* was 47.85 days under a similar environmental conditions (Ayvaz *et al*., 2007). Based on our findings, the immature development time of *C. maculatus* was shorter than those reported in the earlier studies. Fox *et al*. (2004) found that the development time of *C. maculatus* reared on cowpea and mung bean was about 30 days at 25°C. Based on Kazemi *et al*. (2009) development time of *C. maculatus* were recorded 39.53, 34.94, 37.43, and 42.66 days on mung bean, cowpea, chickpea, and lentil, respectively, under the same conditions as ours.

Plant species differ greatly in suitability as hosts for specific pest when measured in terms of survival, development and reproductive rates of the pest. Thus, presence of nutrients and defensive chemicals in plants, presence of repellent or attractive volatile compounds, presence and density of glandular and/or non-glandular trichomes on plant leaf and stem surfaces are the most important factors, which affect host acceptability and reproductivity of the pest (Hoy, 2011).

Female adult longevity of *E. kuehniella* (7.6 days) was shorter than *C. maculatus* (15.5 days). Female adult longevity of both pests was shorter than their males. It is plausible because both the pest species are protogynous where females emerge slightly earlier than males (Xu & Wang, 2008). Female adult longevity of both species was found lower than those revealed by previous studies. Depending on the rearing on different varieties, *E. kuehniella* female adult longevity was at least 8 days (Tarlack *et al.,* 2015) which is slightly longer than our results, considering difference in experimental temperature. Similarly, *E. kuehniella* female adult longevity was longer than our results (9.87 days) under the same temperature regime as in our study (Pakyari *et al*., 2016). Female adult longevity of *C. maculatus* was reported as 19-22 days at 25 °C and 9.28 days at 30 °C (Fox *et al*., 2004; Arjanbhai, 2015).

Pre-oviposition (0.3 days) and oviposition (3.90 days) periods of *E. kuehniella* were shorter than the values reported in previous studies. Tarlack *et al*. (2015) reported pre-oviposition and oviposition periods for *E. kuehniella* 1.26-1.53 days and 4.73-5.46 days, respectively, at 28°C reared on flours of different varieties. Fecundity of *E. kuehniella* (203.30 eggs) was lower than the results of Pakyari *et al*. (2016) and Tarlack *et al*. (2015). Such considerable variation in fecundity may be due to the differences in mass rearing techniques. Lower number of egg production by *E. kuehniella* in our study may be due to their physiological fitness during shorter oviposition period i.e. decline in ovarial development or changes in biological behaviors (Kim & Lee, 2008). Lower number and probable lower quality of *E. kuehniella* urge comparative life table studies of this pest under different temperatures and humidity regimes on different host plants and varieties for the development of optimal rearing conditions. The result of the oviposition period of *C.*

maculatus in our study (4.9 days) was lower than those reared on green gram and chickpea while longer than those reared on cowpea and lentil under same temperature regime (Kazemi *et al*., 2009). Our results regarding the fecundity of *C. maculatus* (95.50 eggs / female) is higher than all *C. maculatus* cultures reared on the aforementioned host plant seeds (Kazemi *et al*., 2009). Pre-oviposition and oviposition periods of *C. maculatus* on cowpea, chickpea, and soybean at 30 °C were higher than those obtained in our study, while the results of fecundity were still higher than those reported in earlier studies (Arjanbhai, 2015). Moreover, the fecundity of *C. maculatus* was higher than those from another study including the same host plant and the same temperature regime (Sedaghat *et al*., 2014). Variations in fecundity of the both pests may occur between biological responses of different insect species to environmental conditions such as temperature and humidity.

The net reproductive rate of the moth was higher than the weevil, while the intrinsic rate of increase was lower in *E. kuehniella* than *C. maculatus*. This is due to fact that the inverse relationship of the intrinsic rate of increase (*r*) with the mean generation time (*T*). The intrinsic rate of natural increase value of *C. maculatus* was similar to that reported by Sedaghat *et al*. (2014) but higher than the estimated value by Kazemi *et al*. (2009). Value of the intrinsic rate of increase is the best indicator for the physiological attributes of an insect regarding its capability to increase; therefore, it can be used to forecast the prospective severity of the insect pests (Roy *et al*., 2003; Razdoburdin, 2006; Negloh *et al*., 2008).

Differences in life cycle parameters between our results and earlier studies are expected due to experimental conditions, however our results may be exploited for optimization of rearing procedures of both pests along with their biocontrol agents such as predators and parasitoids; for example, the egg parasitoids belonging to the family Trichogrammatidae (Hymenoptera). Therefore, effects of abiotic (temperature, humidity, the diet properties, food accessibility, grain moisture, content and its morphological properties, construction materials of storages) (Bellows *et al*., 1992; Gillooly *et al.,* 2002; Žnidarčič *et al*., 2008; Golizadeh *et al*., 2010; Žnidarčič *et al*., 2011) and biotic (perturbation of pest densities and biological interactions among organisms including predators, parasitoids, vertebrates, cannibalism, flock, and entomopathogens) factors on life table and population dynamics of insects should not be underestimated (Chapman, 1928; Boyce, 1946; Cox & Collins, 2002).

Variations in the stage structure can be explained based on the results of population projection data extracted from the age-stage, two-sex life table data. Since female age-specific life tables cannot consider stage differentiation, it is impossible to depict the stage structure using such traditional life tables (Birch, 1948; Huang & Chi, 2012). A comprehensive understanding of the stage structure of insect pests is crucial in IPM because their distribution, expansion rate, and injury potential vary with stages (Chi, 1990).

The immature developmental time, adult longevity, and fecundity of *E. kuehniella* were significantly higher than *C. maculatus*. Quite surprisingly, within shorter oviposition period,

females of *E. kuehniella* laid two folds eggs as *C. maculatus* females. Probably the genetic ability and the longer developmental time allowed the moth to emerge with more stored energy for laying higher numbers of eggs (Watt *et al*., 1992). Thus, the moth could produce more progeny.

An effective control practice against the stored product pests may benefit from a life table based integrated pest management approach. Therefore, further experiments involving the effects of various biotic and abiotic factors on life history and population growth parameters of both pests are needed.

References

Akca, I., Ayvaz T., Yazici, E., Smith, C. L. & Chi, H. (2015) Demography and population projection of *Aphis fabae* (Hemiptera: Aphididae): with additional comments on life table research criteria. *Journal of Economic Entomology* 108(4), 1466-1478.

Akköprü, E. P., Atlıhan, R., Okut, H. & Chi, H. (2015) Demographic assessment of plant cultivar resistance to insect pests: a case study of the dusky-veined walnut aphid (Hemiptera: Callaphididae) on five walnut cultivars. *Journal of Economic Entomology* 108(2), 378-387.

Arjanbhai, C. J. (2015) *Biology, life table and management of Callosobruchus maculatus (Fabricius) on different stored pulses.* PhD Dissertation, Junagadh Agricultural University, India.

Ayvaz, A., Albayrak, S. & Tunçbilek, A. Ş. (2007) Inherited sterility in Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae): Effect of gamma radiation on insect fecundity, fertility and developmental period. *Journal of Stored Products Research* 43(3), 234-239.

Azadi, E., Sadeqi, A., Güncan, A., Khanjani, M., Bbolhavaeji, H. & Maroufpoor, M. (2018) Demographic Comparison of the *Tetranychus urticae* Koch. (Acari: Tetranychidae) Reared on Different Cultivars of Strawberry. *Journal of Economic Entomology* 111 (6), 2927–2935.

Bellows, Jr. T. S., Van Driesche, R. G. & Elkinton, J. S. (1992) Life-table construction and analysis in the evaluation of natural enemies. *Annual Review of Entomology* 37, 587-612.

Birch, L. C. (1948) The intrinsic rate of natural increase of an insect population. *Journal of Animal Ecology* 1, 15-26.

Boyce, J. M. (1946) The influence of fecundity and egg mortality on the population growth of *Tribolium confusum* Duval. *Ecology* 27, 290-302.

Carey, J. (1982) Demography of the twospotted spider mite, *Tetranychus urticae* Koch. *Oecologia* 52, 389-395.

Carey, J. R. (2001) Insect biodemography. *Annual Review of Entomology* 46(1), 79-110.

Campolo, O., Giunti, G., Russo, A., Palmeri, V. & Zappal`a L. (2018) Essential Oils in Stored Product Insect Pest Control. *Journal of Food Quality* 4, 1-18.

Chapman, R. N. (1928) The quantitative analysis of environmental factors. *Ecology* 9, 1-22.

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology* 17, 26-34

Chi, H. (1990) Timing of Control Based on the Stage Structure of Pest Populations: A Simulation Approach. *Journal of Economic Entomology* 83, 1143-1150.

Chi, H. (2017a,b) TWOSEX-MSChart: a computer program for the age-stage, two-sex life table analysis. *http://140.120.197.173/Ecology/Download/TWOSEX-MSChart.rar.*

Chi, H. (2017b) Timing-MSChart: Computer program for population projection based on age-stage, two-sex life table. *http://140.120.197.173/Ecology/Download/TIMING-MSChartrar.*

Chi, H. & Liu, H. (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology, Academia Sinica* 24, 225-240.

Chi, H. & Su, H. Y. (2006) Age-stage, two-sex life tables of *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae) and its host *Myzus persicae* (Sulzer) (Homoptera: Aphididae) with mathematical proof of the relationship between female fecundity and the net reproductive rate. *Environmental Entomology* 35(1), 10-21.

Cox, P. & Collins, L. (2002) Factors affecting the behaviour of beetle pests in stored grain, with particular reference to the development of lures. *Journal of Stored Products Research* 38(2), 95-115.

Devi, M. B. & Devi, N. V. (2014) Biology and morphometric measurement of cowpea weevil, *Callosobruchus maculatus* fabr. (Coleoptera: Chrysomelidae) in green gram. *Journal of Entomology and Zoology Studies* 2, 74-76.

Fox, C. W., Bush, M. L., Roff, D. A. & Wallin, W. G. (2004) Evolutionary genetics of lifespan and mortality rates in two populations of the seed beetle, *Callosobruchus maculatus*. *Heredity* 92(3), 170-181.

Gholizadeh, A., Kamali, K., Fathipour, Y. & Abbasipour, H. (2010) Life table of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) on five cultivated brassicaceous host plants. *Journal of Agricultural Science and Technology* 11,115-124.

Gillooly, J. F., Charnov, E. L., West, G. B., Savage, V. M. & Brown, J. H. (2002) Effects of size and temperature on developmental time. *Nature* 417(6884), 70-73.

Gonçalves, C., Amaro, F., Figueiredo, E., Godinho, M. & Mexia, A. (2005) Productivity and quality aspects concerning the laboratory rearing of *Trichogramma* spp. (Hym: Trichogrammatidae) and its factitious host, *Ephestia kuehniella* Zeller (Lep.: Pyralidae). *Boletín de Sanidad Vegetal. Plagas* 31, 19-23.

Goodman, D. (1982) Optimal life histories, optimal notation, and the value of reproductive value. *American Naturalist* 119, 803-823.

Hamasaki, K. & Matsui, M. (2006) Development and reproduction of an aphidophagous coccinellid, *Propylea japonica* (Thunberg) (Coleoptera: Coccinellidae), reared on an alternative diet, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs. *Journal Applied Entomology and Zoology* 41(2), 233-237.

Hoy M. A. (2011) *Agricultural Acarology: Introduction to integrated mite management.* CRC Press, New York, pp. 410.

Huang, Y. B. & Chi, H. (2012) Age-stage, two-sex life tables of *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) with a discussion on the problem of applying female age-specific life tables to insect populations. *Journal of Insect Science* 19(2), 263-273.

Kazemi, F., Talebi, A. A., Fathipour, Y. & Farahani, S. (2009) A comparative study on the effect of four leguminous species on biological and population growth parameters of *Callosobruchus maculatus* (F.) (Col.: Bruchidae). *Advances in Environmental Biology* 3(3), 226-232.

Khanamani, M., Fathipour, Y. & Hajiqanbar, H. (2013) Population growth response of *Tetranychus urticae* to eggplant quality: application of female age-specific and age-stage, two-sex life tables. *International Journal of Acarology* 39(8), 638-648.

Kim, D. S. & Lee, J. H. (2008) Phylogeny simulation model of *Scotinophara lurida* (Hemiptera: Pentatomidae). *Environmental Entomology* 37, 660-669.

Kim, D. S. & Riedl, H. (2005) Effect of temperature on development and fecundity of the predaceous plant bug *Deraeocoris brevis* reared on *Ephestia kuehniella* eggs. *BioControl* 50(6), 881-897.

Negloh, K., Hanna, R. & Schausberger, P. (2008) Comparative demography and diet breadth of Brazilian and African populations of the predatory mite *Neoseiulus baraki*, a candidate for biological control of coconut mite. *Biological Control* 46(3), 523-531.

Nikooei, M., Fathipour, Y., Jalali Javaran, M. & Soufbaf, M. (2015) How different genetically manipulated Brassica genotypes affect life table parameters of *Plutella xylostella* (Lepidoptera: Plutellidae). *Journal of Economic Entomology* 108, 515-524.

Pakyari, H., Amir-Maafi, M. & Moghadamfar, Z. (2016) Oviposition Model of *Ephestia kuehniella* (Lepidoptera: Pyralidae). *Journal of Economic Entomology* 109(5), 2069-2073.

Rahman, A. & Talukder, F. A. (2006) Bioefficacy of some plant derivatives that protect grain against the pulse beetle, *Callosobruchus maculatus*. *Journal of Insect Science*, 6(3), 1-10.

Rajendran, S. & Sriranjini, V. (2008) Plant products as fumigants for stored-product insect control. *Journal of Stored Products Research* 44:126-135.

Razdoburdin, V. (2006) Influence of the spider mite, *Tetranychus urticae* Koch (Acarina, Tetranychidae) population density on its dynamics on different cucumber cultivars. *Entomological Review* 86(4), 398-408.

Roy, M., Brodeur, J. & Cloutier, C. (2003) Effect of temperature on intrinsic rates of natural increase (r_m) of a coccinellid and its spider mite prey. *BioControl* 48, 57-72.

Sallam, M. N. (2008) Insect Damage: Damage on Post-Harvest. Available from: *http://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_Pests-Insects.pdf* (accessed 12 January 2019).

Safuraie-Parizi, S., Fathipour, Y. & Talebi, A. A. (2014) Evaluation of tomato cultivars to *Helicoverpa armigera* using two-sex life table parameters in laboratory. *Journal of Asia-Pacific Entomology* 17(4), 837-844.

Sedaghat, R., Talebi, A. A. & Moharramipour, S. (2014) Effects of ultraviolet irradiation on life table of cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of the Entomological Research Society* 16(2), 1-12.

Sedlacek, J. D., Weston, P. A. & Barney, J. (1996) *Lepidoptera and Psocoptera. In: Integrated management of insects in stored products,* CRC Press, New York, pp 41–70.

Tarlack, P., Mehrkhou, F. & Mousavi, M. (2015) Life history and fecundity rate of *Ephestia kuehniella* (Lepidoptera: Pyralidae) on different wheat flour varieties. *Archives of Phytopathology and Plant Protection* 48(1), 95-103.

Tiroesele, B., Thomas K. & Seketeme, S. (2015) Control of Cowpea Weevil, *Callosobruchus Maculatus* (F.) (Coleoptera: Bruchidae), Using Natural Plant Products. *Insects* 6,77-84.

Watt, W. B. (1992) Eggs, enzymes, and evolution: natural genetic variants change insect fecundity. *Proceedings of the National Academy of Sciences of the United States of America* 89(22), 10608-10612.

Xu, J. & Wang, Q. (2008) Male moths undertake both pre-and in-copulation mate choice based on female age and weight. *Behavioral Ecology and Sociobiology* 63 (6), 801-808.

Yu, L. Y., Chen, Z. Z., Zheng, F. Q., Shi, A. Z., Guo, T. T., Yeh, B. H., Chi, H. & Xu, Y. Y. (2013) Demographic analysis, a comparison of the jackknife and bootstrap methods, and predation projection: a case study of *Chrysopa pallens* (Neuroptera: Chrysopidae). *Journal of Economic Entomology* 106 (1), 1-9.

Žnidarčič, D., Marković, D., Vidrih, R., Bohinc, T. & Trdan, S. (2011) Which biophysical and biochemical factors may contribute to higher resistance of cabbage (*Brassica oleraceae* L. var. Capitata) to attack of the most important pests. *Acta Agriculturae Slovenica* 97(2), 151-158.

Znidarcic, D., Valic, N. & Trdan, S. (2008) Epicuticular wax content in the leaves of cabbage (*Brassica oleracea* L. var. capitata) as a mechanical barrier against three insect pests. *Acta Agriculturae Slovenica* 91(2), 361-370.