International Journal of Agriculture, Environment and Food Sciences
JAEFS
e-ISSN : 2618-5946
DOI: 10.31015/jaefs.18006
www.jaefs.com

Research Article
Int J Agric Environ Food Sci 2(2):36-43 (2018)

The life tables of *Chrysomphalus aonidum* and *Coccus hesperidum* under laboratory conditions

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Abstract

Numerous species of insect pest have been found causing serious damage to citrus plants in Turkey. *Chrysomphalus aonidum* (L.) (Diaspididae), and *Coccus hesperidum* L. (Coccidae) from Hemiptera among them are potential insect pest, which cause huge economic losses to citrus. The current study investigated life table parameters of both pests, which included net production rate (R_0), intrinsic rate of increase (r_m), mean generation time (T_0), doubling time (T_2), total production rate (GRR) and finite rate of increment (λ). Results showed that net production rate (R_0) of both *C. aonidum* and *C. hesperidum* were 74.001 and 185.295 female/female/offspring, respectively. The intrinsic rate of increase (r_m) for the pests was calculated as 0.052 and 0.047 female/female/day, respectively. Similarly, the mean generation time (T_0) was recorded 82.030 days for *C. aonidum* and 110.985 days for *C. hesperidum*. The doubling time (T_2), gross reproduction rate (GRR), and finite rate of increase (λ) were recorded 13.320 days, 142.555 eggs/female and 1.054 egg/female/day respectively for *C. aonidum* whereas, in case of *C. hesperidum*, the aforementioned values were calculated as 14.732 days, 579.047 eggs/female and 1.048 eggs/female/day, respectively

Keywords: Brown soft scale, circular scale, life table, pumpkin

Received: 01.02.2018 Accepted: 28.02.2018 Published (online): 10.04.2018

Introduction

Citrus is one of the most important fruits with a total production of 130 million tons, which is grown on an area of about 9 million ha throughout the world. China, Brazil and U.S.A. are the major citrus producing countries, whereas Turkey ranks 9th with a total citrus production of 3.7 million tons, grown on area of 127 thousands ha respectively (FAO, 2014). In Turkey, citrus is mainly grown in the Mediterranean, Aegean, South Marmara and Eastern Black Sea Regions, respectively (Durmuş and Yiğit, 2003). About 1.7 million tons oranges in about 55 thousand ha area, about 950 thousand tons mandarins in about 39 thousand ha area, 726 thousand tons lemons in about 27 thousand ha area, 228 thousand tons grapefruits in about7 thousand ha area, and 3 thousand tons other citrus in about 47 ha area are produced in Turkey (TUIK, 2014). About 34 pathogens, 89 pest insects, 16 nematodes, and 155 weed species that causes economic losses or not were determined in citrus orchards of Turkey (Uygun and Satar, 2008; Karacaoğlu and Satar, 2010). Scale insects, whiteflies and aphids are the most important and potential insect pests among all these species, causing economic losses to citrus growers. Scale insects may cause severe economic damage by sucking leaves and fruits of citrus. The feeding damage caused by scale insects in citrus results in poor quality fruit formation, decreasing of the marketing value and may even cause death of the tree (Uygun et al., 2013).

Chrysomphalus aonidum (L.) (Diaspididae) and *Coccus hesperidum* L. (Coccidae) belong to superfamily Coccoidea. Severe economic damage to citrus plants has been reported by both species. These scales are oviparous pests and their eggs are laid under their female's shell. Crawlers hatched from eggs emerge from under the female scale's shell. Afterwards, the crawlers move over to find a suitable site for feeding and then, they settle on feeding site (Uygun et al., 2013). These pests feed on leaves, twigs and fruits and ultimately cut down the fruit quality. Feeding of *C. aonidum* on citrus leads to a dirty appearance on citrus fruits and resultantly lowers the market value of the produce. *C. hesperidum* damages citrus tree by secreting honeydew on leavestwigs, branches and fruits, which leads to the formation of a dark-colored sooty mold, known as fumagine. Thus, plant parts turn on black, and fruits fall down and also, fruit dump is occurred (Kessing and Mau, 2007; Uygun et al., 2013).

Deevey (1947) stated that life table is a systematic analysis of mortality factors occurring in a population.In the current study, some bioecological parameters of both scale insects (*C. aonidum* and *C. hesperidum*), which included incubation times, hatching rates, settled rates of crawlers, sexual indexes, times of preoviposition, oviposition and postoviposition, daily numbers of eggs were observed on pumpkins (*Cucurbita maxima* Jarrahdale and *Cucurbita moschata* Poir. (Cucurbitales: Cucurbitaceae)). Also, life table parameters were calculated to determine some bioecological parameters which may need when these pests are used as prey for mass production of their natural enemies.

Keeping in mind the economic status of citrus in Turkey, the current investigation was therefore, designed to study the life tables of *C.aonidum* and *C.hesperidum* under laboratory conditions.

Cite this article as : Celikpence, Y., Birgucu, A.K., Karaca, I. (2018). The life tables of *Chrysomphalus aonidum* and *Coccus hesperidum* under laboratory conditions. Int. J. Agric. Environ. Food Sci., 2(2): 36-43. DOI: 10.31015/jaefs.18006
Available online at : https://jaefs.com - http://dergipark.gov.tr/jaefs

Materials and Methods

Breeding of the Scale Pests

Twig parts, leaves and fruits infested with *Chrysomphalus aonidum* and *Coccus hesperidum* were initially collected from citrus farms at Antalya in 2012. Then, these infected plant parts were placed on clean pumpkins in a climatic room with 25±1ºC temperature, 60±5% relative humidity and 16:8 h. (light:dark) photoperiod conditions. Pumpkins(*Cucurbita maxima* and *Cucurbita moschata*)were used as hosts for *C. aonidum* and *C. hesperidum*, respectively. In this manner, contamination of newly hatched crawlers to the clean pumpkins in 28.0x37.2x7.5 cm size plastic trays was provided. Later on, increasing and continuity of scale pest production were ensured by adding new clean pumpkins in the trays.

The identification of *C. aonidum* was kindly performed by Prof.Dr. M. Bora KAYDAN (Çukurova University, Imamoglu Vocational School, Adana, Turkey).

Establishment of Experiments

Eggs laid by female adults on pumpkins infected with the scale pests were transferred to the same kind of pumpkins by gently touching with the tip of the fine paintbrush. The lights of climatic chamber were kept off for 24 hours in order to accelerate the egg hatching process and settlement of newly hatched crawlers (Karaca et al., 1987). Settlement of newly born crawlers on pumpkins was monitored, and afterwards, square cells about 2x2 cm were drawn with Tanglefoot® trademark a special stickem around the settled crawlers on pumpkins. Crawlers in the cells were observed every day, until they became adult and till their death. Each cell was considered as a replicate. Mortality, discrimination of male and female individuals, duration of preoviposition, oviposition and postoviposition of crawlers in the cells were recorded by referencing the age-mate individuals from out of cells on the same pumpkin. After mating of adult female scales, two female scales were left in each cell in experiment related to *C. aonidum*. However, one female scale was left in each cell in experiment related to *C. hesperidum* and the remaining female scales were removed from the cells in both experiments.Later on, newly hatched progenies of mated female scales left in the cells were counted daily. The experiments related to both of *C. aonidum* and *C. hesperidum* were conducted in a climatic chamber set to 25ºC temperature, 60% relative humidity and 16:8 h. photoperiod.

Life Table Analyses

Life table parameters were calculated by using RmStat-3 programmer (Özgökçe and Karaca, 2010). Intrinsic rate of increase (r_m, female/female/day) by taking advantage from Euler-Lotka equation ($\sum e^{(-r_m.x)} l_x.m_x = 1$) and net reproductive rate ($R_0 = \sum l_x.m_x$) female/female/offspring), i.e. the mean number of offsprings, which are laid by a female in her lifetime were calculated according to Birch (1948). Where "l_x" is the age-specific survival rate and "m_x," is fecundity rate (female/female) which is computed by multiplying the mean number of offspring by the sexual ratio (Birch, 1948).

Also following parameters were calculated:

Mean generation time (day), $T_o = \frac{\ln R_0}{r_m}$ (Birch, 1948),

Gross reproduction rate (egg/female), $GRR = \sum m_x$ (Birch, 1948),

Finite rate of increase (egg/female/day), $\lambda = e^{r_m}$ (Birch, 1948),

Theoretical population-doubling time (day), $T_2 = \frac{\ln 2}{r_m}$ (Kairo and Murphy, 1995),

Reproductive value (female/female), $V_x = \frac{\sum_{y=x} (e^{r_m.y}.l_y.m_y)}{l_x.e^{-r_m.x}}$ Imura, 1987),

Life expectancy (day), $E_x = \frac{\sum_{y=x} \frac{(l_y+l_{y+1})}{2}}{l_x}$ (Carey, 1993; Southwood, 1978),

Stable age distribution, $C_x = \frac{l_x.e^{-r_m.x}}{\sum_{x=0}(l_x.e^{-r_m.x})}$ (Birch, 1948).

Where "x" is the female's age in days, "e" is Euler's number which is a mathematical constant (approximately equal to 2.71828).

Two-parameter Weibull distribution model was used to describe age-specific survival rate (l_x) of the pests (Deevey, 1947; Pinder et al., 1978; Tingle and Copland, 1989; Wang et al., 2000). The parameters of this distribution model were calculated according to the following formula:

$$S_p(x) = e^{\left[-\left(\frac{x}{b}\right)^c\right]} \qquad x, b, c > 0$$

Where "$S_p(x)$" is the probability of survival at x age, "x" is the female's age in days, "b" is a scale parameter and "c" is a shape parameter. The shape parameter of the curve belonged to the age-specific survival rate c>1, c=1 or c<1 correspond to Deevey's (1947) type I, II or III survivorship curves, respectively (Pinder et al., 1978; Tingle and Copland, 1989; Wang et al., 2000). Also, description of the age-specific fecundity rates (m_x) of the pests was performed by Enkegaard regression model (Enkegaard, 1993; Hansen et al., 1999).

$$F_{(x)} = a.x.e^{(-bx)}$$

Where "$F_{(x)}$" is the probability of fecundity at x age (female/female/day), "x" is the female's age in days, "a" and "b" are constant parameters, e: Euler's number which is mathematical constant (approximately equal to 2.71828).

The parameters and the coefficients of determination (R^2) in both models were obtained by using SigmaPlot® (Version 11.0, Systat Software, Inc., San Jose California, USA) package program.

Results and Discussion

Previous study conducted by Serag (1998) on biological cycle of *Chrysomphalus aonidum* reported that mean times of preoviposition, oviposition and postoviposition of the pest were 6.79, 6.38 and 5.56 days, respectively. Similarly, Serag (1998) further stated that the number of daily fecundity was 13.96 eggs/female/day and the number of total fecundity was 88.07 eggs/female. The pest may give 3-6 generations each year (Alkan, 1953; Uygun et al., 2013) and overwinters as the first and secondstage nymphs in Turkey (Tunçyürek and Öncüer, 1974). The mortality rate of *C. dictyospermi* in the first and second nymphal stages due to abiotic factors was 78% in Georgia (Chkhaidze and Yasnosh, 2001) and 40% in Turkey (Tunçyürek-Soydanbay and Erkin, 1981). Salama (1970) suggested that optimum development temperature and relative humidity for this pest was 22-25ºC and 50-58%. The present study demonstrated that adult lifespan of *C. aonidum* was 121 days (Table 1). However, Hlavjenková and Šefrová (2012) reported that *Chrysomphalus dictyospermi* was a devastating pest of ornamental plants in Czech Republic. Also, the further authors stated that sexual index of this pest was 0.82/1 (male/female), hatching time of its eggs was 10 days, and adult lifespan was 62 days, respectively.

Coccus hesperidum deposits its eggs under female scale's shell, and after hatching, crawlers may feed under female's shell for 3-4 days. Later on, the crawlers moved out from mother's shell, 85% of which settle on the food for active feeding in 1-2 days (Serag, 1998). Also in the present study, the crawlers moved out from mother's shell in 2-3 days and then, settled on the pumpkin in 1 day. In additionally, Serag (1998) pointed out that the mean development times of the first and second stage nymphs of this pest were 7.62 and 10.74 days, respectively and total development time of the pest was 41.4 days. Similarly, in the current study, total development time of the pest was recorded as 52.09 days (Table 1). Reed et al. [23] declared that the mean development time was 33 days. Annecke (1959) studied that adult lifespan of *C. hesperidum* was approximately 90-125 days under hot weather conditions, and also it was reported that the development time of this pest was 40-60 days (Gill, 1988; Kosztarab, 1996; Malais and Ravensberg, 2003).

Serag (1998) reported that duration of preoviposition, oviposition and postoviposition were 7.85, 5.61 and 9.59 days, respectively. However, in the present study, durations of these biological stages were calculated as 40.95, 67.72 and 31.38 days, respectively. Kessing and Mau (2007) reported that daily fecundity of *C. hesperidum* was 5-19 eggs per female, and total eggs laid by a female for 30-65 days was 80-250 eggs. The present study found that the daily fecundity and total fecundity were 4.07 eggs/female/day and 579.05 eggs/female, respectively (Table 1).

The net production rates (R_0) of *C. aonidum* and *C. hesperidum* were 73.963 and 246.920 females/female/offspring, respectively. The intrinsic rates of increases (r_m) for the pests were calculated as 0.052 and 0.047 females/female/day, respectively. The mean generation time (T_0) was calculated as 82.030 days for *C. aonidum*, and was determined as 110.985 days for *C. hesperidum*. The doubling time (T_2), total production rate (GRR) and finite rate of increment (λ) were recordedas 13.320 days, 142.555 eggs/female and 1.054 eggs/female/day, respectivelyfor *C. aonidum*. In case of *C. hesperidum*, the aforementioned values were calculated as 14.732 days, 579.047 eggs/female and 1.048 egg/female/day, respectively (Table 2).

Table 1. Mean development times, fecundities and lifespans of *Chrysomphalus aonidum* and *Coccus hesperidum* under laboratory conditions

	Species	N	Mean±SEM
Development time	*C. aonidum*	211	30.00±0.71
	C. hesperidum	65	52.09±0.05
Preoviposition time	*C. aonidum*	121	34.06±0.32
	C. hesperidum	64	40.95±0.22
Oviposition time	*C. aonidum*	121	54.49±0.20
	C. hesperidum	64	67.72±0.48
Postoviposition time	*C. aonidum*	121	2.88±0.07
	C. hesperidum	64	31.38±0.53
Lifespan	*C. aonidum*	121	91.69±2.78
	C. hesperidum	64	140.05±1.86
Generation time	*C. aonidum*	121	65.32±0.15
	C. hesperidum	64	94.05±0.19
Daily fecundity	*C. aonidum*	121	1.54±0.10
	C. hesperidum	64	4.07±0.12
Total fecundity	*C. aonidum*	121	244.46±4.05
	C. hesperidum	64	579.05±17.48

Table 2. Life table parameters of *Chrysomphalus aonidum* and *Coccus hesperidum*

Parameters	*C. aonidum*	*C. hesperidum*
Intrinsic rate of increase, r_m	0.052	0.047
Net reproductive rate, R_0	74.001	185.295
Mean generation time, T_0	82.030	110.985
Theoretical population-doubling time, T_2	13.320	14.732
Gross reproduction rate, GRR	142.555	579.047
Finite rate of increase, λ	1.054	1.048
N	233	150

Curves of the survival rate (l_x), stable age distribution (C_x) and life expectancy (E_x) of *C. aonidum* given in Figure 1. Based on the results, the whole adult females of the pest were died on the124th day of the experiment. The survival rate of the pest began to decrease after the 27th day, and was counted as 0.03 on the 124th day. The stable age distribution shows the relationship between the number of individuals in the current age and the initial number of individuals of an organism. Due to the increase in the number of neonate individuals who participated in the population with the increment of reproductive rate of the population, an increase was seen in the stable age distribution, which was initially 0.06. Thus, the stabile age distribution was reached the top level with 1.00 values on the 124th day, by adding age distribution value at each age. The life expectancy of initially 80.81 values showed a decrease until the 39th day and then, reached the initial value on the 40th day, due to encountered deaths. Afterwards, it showed again a decrease in a fixed manner until the 122nd day, but it could not go back upward as in the 40th day, due to quite low survival as 0.12 proportions (Figure 1).

The generation time of *C. aonidum* was calculated approximately 64 days (Table 1 and Figure 2). The reproductive value of females (V_x) was reached the top level on the 64th day. According to fecundity rate curve, the first egg production was realized on the 64th day, and after this day, fecundity rate was began to decline in proportion to the reproductive value of females (V_x). The maximum daily egg production of the pest was on the 69th day with 3.89 eggs/day, and last egg production was noticed on the 122nd day of the experiment (Figure 2).

The age-specific survival rate (l_x) of *C. aonidum* was described by two-parameter Weibull distribution model. The parameters "b" and "c" of the model was found as 47.55±2.98 and 1.40±0.14 (R^2= 0.62), respectively. Based on these results, it is possible to say that the population of *C. aonidum* had the Type 1 survivorship curve, which means the increasing population type (Figure 3).

The Enkegaard regression model was applied on the age-specific fecundity rate (m_x) of *C. aonidum*, and the coefficient of determination (R^2) was used as suitability criteria of the model on the data (Kontodimas et al., 2004). However, this model could not be obtained satisfactory fit. The parameters "a" and "b" of the model were 0.78±0.07 and 0.07±0.00 (R^2= 0.46), respectively (Figure 4).

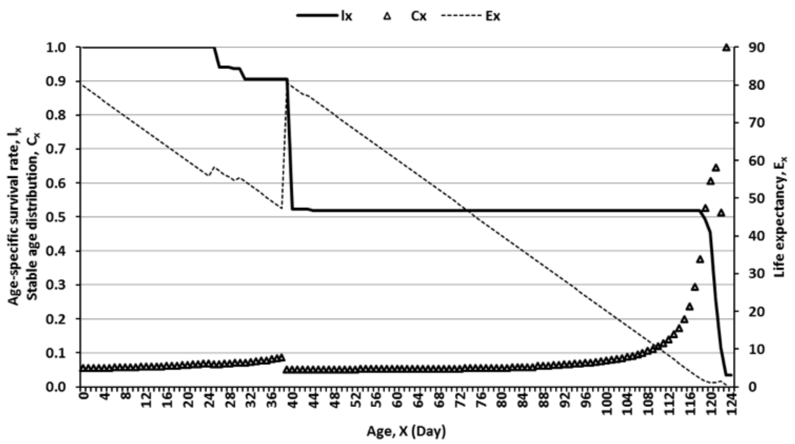

Figure 1. The age-specific survival rate (l_x), stable age distribution (C_x) and life expectancy (E_x) of *Chrysomphalus aonidum* under laboratory conditions.

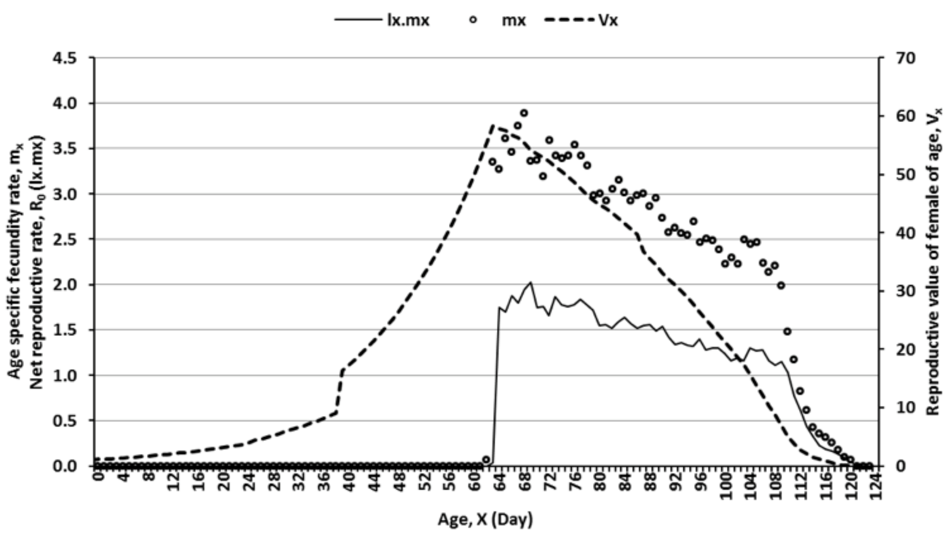

Figure 2. The Fecundity rate (m_x), net reproductive rate (R_0) and reproductive value (V_x) of *Chrysomphalus aonidum* under laboratory conditions.

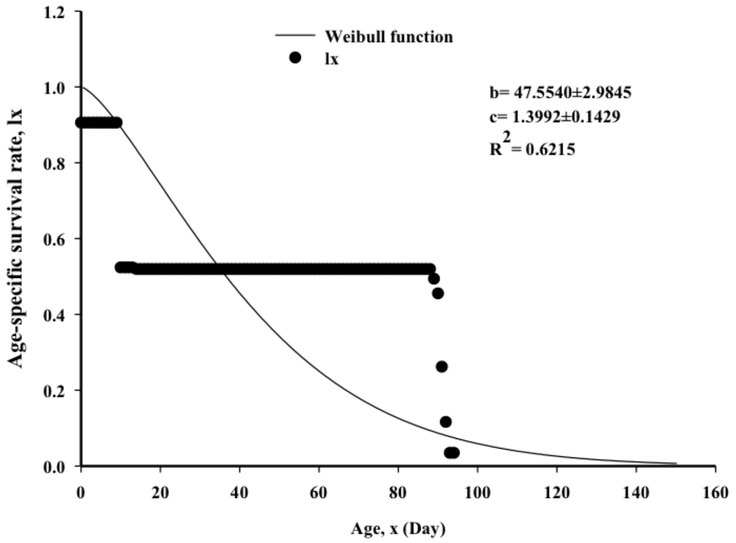

Figure 3. The Weibull function of the age-specific survival rate (l_x) of *Chrysomphalus aonidum*.

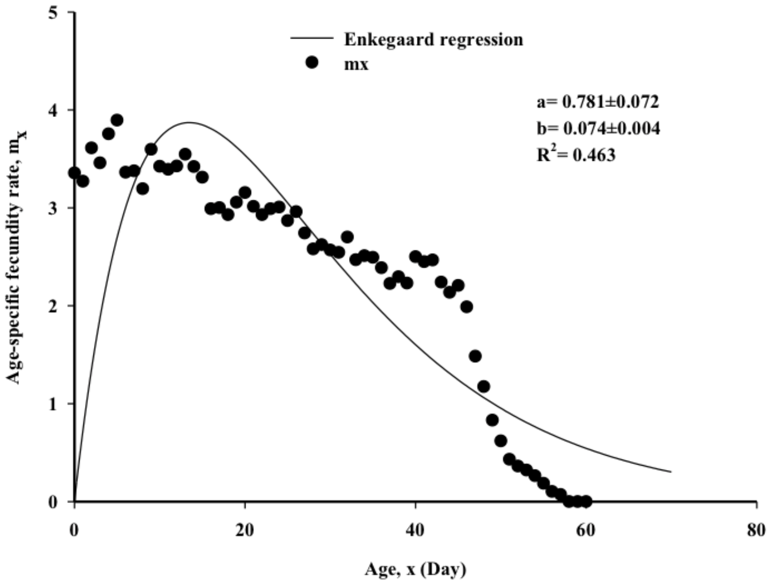

Figure 4. The Enkegaard regression of the age-specific fecundity rate (m_x) of *Chrysomphalus aonidum*.

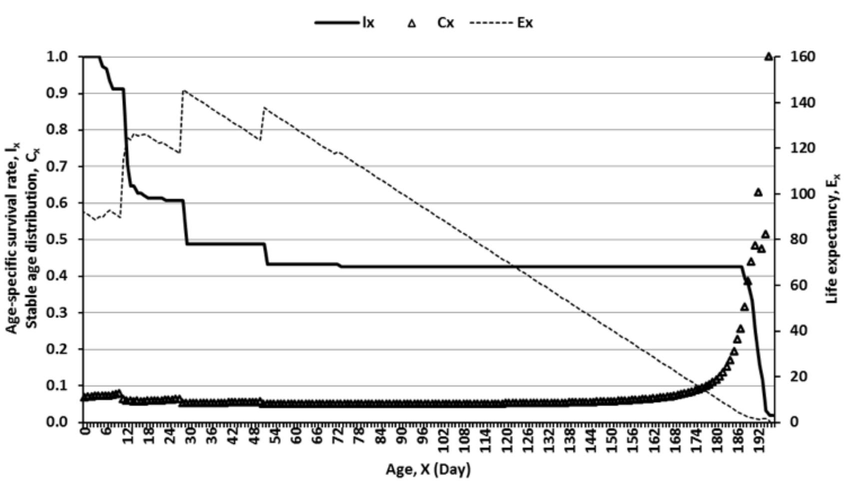

Figure 5. The age-specific survival rate (l_x), stable age distribution (C_x) and life expectancy (E_x) of *Coccus hesperidum* under laboratory conditions

The survival rate (l_x), stable age distribution (C_x) and life expectancy (E_x) of *C. hesperidum* were shown in Figure 5. The survival rate of the pest began to decrease after the 5^{th} day of the experiment and reached the 0.02 proportion on the 196^{th} day. The stable age distribution of initially 0.07 showed an increase after the 149^{th} day of the experiment due to the increase in the number of neonate individuals who participated in the population with the increment of reproductive rate of the population. The life expectancy of initially 92.62 values showed an increment after the 12^{th} day because of encountered deaths and then, reached the highest level on the 29^{th} day with 145.51 values (Figure 5).

The elapsed time from hatching of the pest until the time of egg-laying again after emergence as adult, which means the generation time was approximately 94 days (Table 1 and Figure 6). The reproductive value of females (V_x) was reached the top level on the 94^{th} day. Based on the fecundity rate curve too, the first egg production was realized on the 94^{th} day. Also, the fecundity rate started to decline in parallel with the reproductive value of females (V_x) after this day. The pest reached the maximum level of daily fecundity rate on the 96^{th} day with 18.28 eggs per day (Figure 6).

The age-specific survival rate (l_x) of *C. hesperidum* was described by two-parameter Weibull distribution model. The parameters "b" and "c" of the model was found as 38.72±4.22 and 0.81±0.08 (R^2= 0.45), respectively. Based on the coefficient of determination (R^2), the Weibull model could not be obtained satisfactory fit. However, although the low coefficient of determination, it is possible to say that the population of *C. hesperidum* followed a decline trend due to the high residual sum of squares (RSS= 61.98) of this model (Figure 7).

The parameters "a" and "b" of the Enkegaard regression model applied on the age-specific fecundity rate (m_x) of *C. hesperidum* were 3.71±0.31 and 0.09±0.00 (R^2= 0.70), respectively. Based on the coefficient of determination (R^2), the Enkegaard regression model could be obtained satisfactory fit (Figure 8).

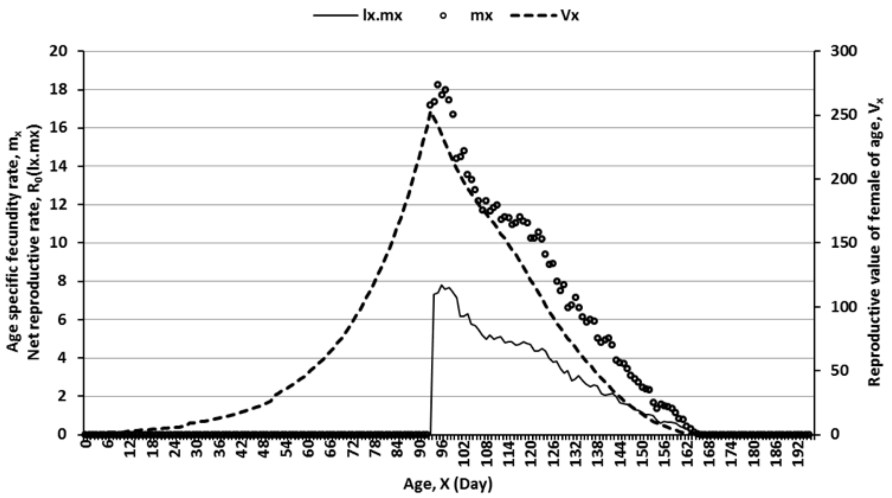

Figure 6. The Fecundity rate (m_x), net reproductive rate (R_0) and reproductive value (V_x) of *Coccus hesperidum* under laboratory conditions.

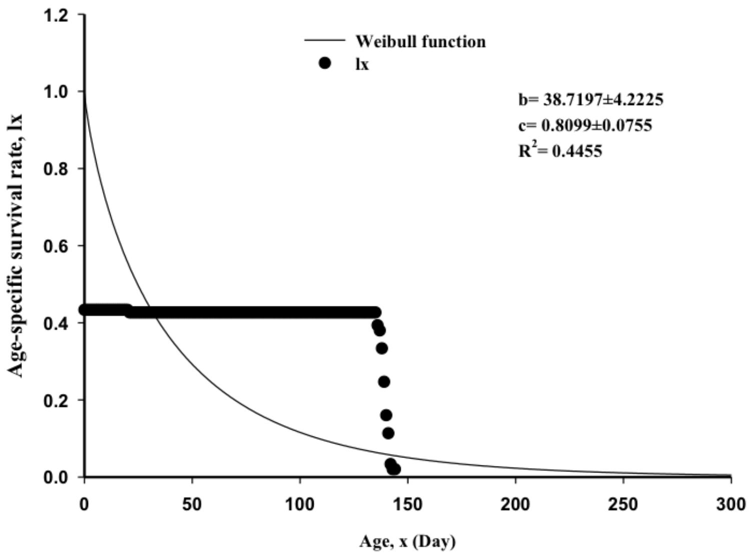

Figure 7. The Weibull function of the age-specific survival rate (l_x) of *Coccus hesperidum*.

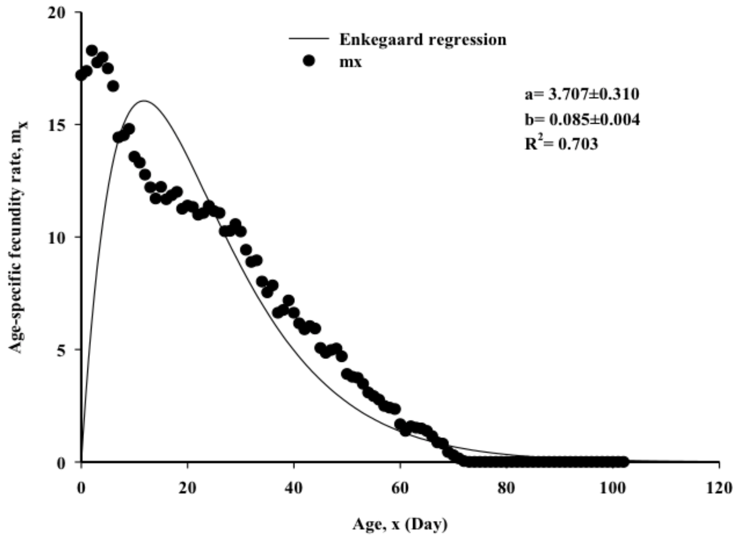

Figure 8. The Enkegaard regression of the age-specific fecundity rate (m_x) of *Coccus hesperidum*.

The present study found some bioecological characteristics of both *C. aonidum* and *C. hesperidum*. Based on the Weibull function of the age-specific survival rate (l_x) of *C. aonidum*, the population level of this pest followed an increase trend. According to our results, it is understood that the pest has a potential to be a feasible prey in the production of beneficial insects in terms of time and economic. Also, population level trend during mass production of this pest under laboratory conditions can be assumed by using this obtained Weibull distribution model. In additionally, fecundity level of the pest in oviposition period was simulated by the Enkegaard regression model.

Acknowledgments

This study is a part of M.Sc. thesis performed by the first author in the Graduate School of Natural and Applied Sciences in Süleyman Demirel University. We are grateful to Prof. Dr. M. Bora KAYDAN (Çukurova University, İmamoğlu Vocational School, Adana, Turkey) for the determination of *C. aonidum*. We would like to thank Scientific Research Projects Management Department of Süleyman Demirel University for their financial support to our study with the project number 4170-YL1-14. Also, the study was presented as a poster at the 67th International Symposium on Crop Protection which was held in Ghent (Belgium) on May 19, 2015. Also, we are most grateful to the two anonymous reviewers for their detailed and very helpful feedback. Meanwhile, we declare that the authors have no conflict of interest.

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