Türk. entomol. derg., 2018, 42 (1): 13-22
DOI: http://dx.doi.org/10.16970/entoted.341521

ISSN 1010-6960
E-ISSN 2536-491X

Original article (Orijinal araştırma)

Population features of biparental and uniparental forms of the oleander scale, *Aspidiotus nerii* Bouché, 1833 (Hemiptera: Diaspididae) on squash

Zakkum kabuklubiti, *Aspidiotus nerii* Bouché, 1833 (Hemiptera: Diaspididae)'nin tek ve çift eşeyli formlarının kabak üstünde popülasyon özellikleri

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Abstract

Aspidiotus nerii Bouché, 1833 (Hemiptera: Diaspididae) is a cosmopolitan pest, mainly found in tropical and subtropical regions. It has been reported from hosts corresponding to more than 100 plant families. Particularly important is the damage caused on lemon and olive trees and ornamental plants such as oleander. It has both biparental and uniparental forms. To investigate the population dynamics of both forms of pest, life tables were constructed under controlled conditions in 2016. The studies were carried out on squash in climatic cabinet adjusted to 25±1ºC, 65±1% RH and 16:8 h L:D photoperiod. At the end of the study, life table parameters of both forms of pest were calculated. Namely intrinsic rate of increase (*r*), 0.039 and 0.042 d^{-1}; finite rate of increase (λ), 1.040 and 1.043 d^{-1}; net reproductive rate (R_0), 14.07 and 27.19 d^{-1}; mean generation time (T), 67.51 and 78.49 d, for biparental and uniparental forms, respectively. R_0 and T were statistically significant different between the two populations. Given these differences, it was estimated that the population size of the uniparental form may be 1.9 times higher than the biparental form.

Keywords: *Aspidiotus nerii*, biparental form, fecundity, two-sex life table, uniparental form

Öz

Aspidiotus nerii Bouché, 1833 (Hemiptera: Diaspididae) esas olarak tropik ve subtropik bölgelerde bulunan yaygın bir türdür. Konukçularının bağlı olduğu bitki familyası sayısının 100'den fazla olduğu rapor edilmektedir. Özellikle limon, zeytin ağaçları ve zakkum gibi süs bitkileri üstünde meydana getirdiği zarar önemlidir. Hem çift eşeyli ve hem de tek eşeyli formlara sahiptir. Zararlının her iki formunun popülasyon dinamiklerini araştırmak için 2016 yılında kontrollü koşullarda yaşam çizelgesi oluşturulmuştur. Çalışmalar, 25±1ºC, %65±1 orantılı nem ve 16:8 A:K şartlarına ayarlanmış iklim kabinlerinde kabak üstünde yürütülmüştür. Çalışma sonunda zararlının her iki formunun yaşam çizelgesi parametreleri sırasıyla: kalıtsal üreme yeteneği (*r*), 0.039 ve 0.042 d^{-1}; artış oranı sınırı (λ), 1.040 ve 1.043 d^{-1}; net üreme gücü (R_o) 14.07 ve 27.19 d^{-1}; ortalama döl süresi (T) 67.51 ve 78.49 gün olarak hesaplanmıştır. Bu parametrelerden R_o ve T istatistiksel olarak önemli bulunmuştur. Bu farklılıklardan dolayı popülasyon tahminlerine göre tek eşeyli formun popülasyon büyüklüğünün çift eşeyli forma göre 1.9 kat daha yüksek olabileceği hesap edilmiştir.

Anahtar sözcükler: *Aspidiotus nerii*, çift eşeyli form, üreme oranı, iki-eşeyli yaşam çizelgesi, tek eşeyli form

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Received (Alınış): 03.10.2017 Accepted (Kabul ediliş): 25.03.2018 Published Online (Çevrimiçi Yayın Tarihi): 26.04.2018

Introduction

Hemiptera species are important insect species that cause economic loses in citrus trees. Some of the most important and economically harmful are the species *Aspidiotus nerii* Bouché, 1833, *Aonidiella aurantii* (Maskell, 1879) (Hemiptera: Diaspididae) and *Planococcus citri* (Risso, 1813) (Hemiptera: Pseudococcidae) (Siscaro et al., 2006). Beardsley & Gonzalez (1975) stated that *A. nerii* is among the principal armored scale pests of the world. Oleander scale is a cosmopolitan species with 455 different host plants (Miller & Ben-Dov, 2004). Oleander scale has both biparental and uniparental forms, which were for the first time described by Felt in 1901 (Gerson & Hazan, 1979). Some authors suggest that cryptic multiple species complexes may also be present (Ferris, 1941; Einhorn et al., 1998; Provencher et al., 2005).

Various investigators have also shown that the behavior, host preferences and biological properties of these two forms of pests also vary. Gerson & Hazan (1979) reported that uniparental forms in Israel are specific to one host (*Pittosporum undulatum* Vent., Pittosporaceae) and that biparental forms naturally occur on different host species. Furthermore, DeBach & Fisher (1956) reported that two sympatric populations of these forms were obtained on oleander (*Nerium oleander* L., Apocynaceae) and English ivy (*Hedera helix* L., Araliaceae). Schmutterer (1952) has pointed out that uniparental forms could only survive indoors in Germany, while biparental forms could also survive in the natural environment and tolerate frost.

The oleander scale is a species that must be carefully monitored due to its serious economic damage to many host plants. The development of effective control methods against both forms and the determination of the correct time for applying management methods require that some details on the life cycle are well known. A limited number of studies on the biology of both forms of this scale have been conducted and, in these studies, the rates of reproduction, development and survival of both forms on different conditions and on different hosts were compared (DeBach & Fisher, 1956; Gerson & Hazan, 1979).

Results of previous investigations revealed that the biparental form showed a higher reproductive rate and shorter developmental time. However, these assessments do not provide enough evidence to understand the population dynamics of a species. Life tables provide comprehensive outputs to understand key-aspects of the life cycle of a given species in a more detailed way. For this reason, this study was undertaken and the biological features of both forms of the oleander scale were investigated. Provencher et al. (2005) reported that existence of uniparental forms adapted to specific hosts can provide enormous practical benefits for the quarantine and control methods, and may even allow better understanding of their ecology and evolution. Oleander scale is known as the best host for production of effective biologic control of pests against scale insects, it is appropriate for use in mass production of both predator and parasitoids in biological control of pests. For example, *A. nerii* is a suitable host for the production of *Aphytis melinus* DeBach, 1959 (Hymenoptera: Aphelinidae) for control of a major citrus pest, *A. aurantii* (Karaca & Uygun, 1993; Gonzalez-Zamora et al., 2012). The objective of our investigation was to determine the life table parameters of biparental and uniparental forms of the oleander scale reared on squash fruit.

Material and Methods

Rearing of insects and experimental area

The study was carried out at the Süleyman Demirel University, Agriculture Faculty, Plant Protection Department, and Biological Control Laboratory in 2016. Squash (*Cucurbita moschata* L. cv. Sunset QHI, Cucurbitaceae) fruit were used for rearing and assaying of biparental and uniparental forms of oleander scale. When active nymphs were settled on the fruit, the surface of each squash was divided into 15-20 areas of 4 cm^2 per individual and surrounded by an adhesive (Tangle-Trap, Tanglefoot, Australia). A total of 191 nymphs were used for biparental assay, and 69 for uniparental assay. Insects were checked daily.

When applied insects became adults, reproduction was estimated by counting and removing all newly emerged nymph each day until all individuals had died. The experiments were conducted in a growth chamber set to 25±1ºC, 65±1% RH and 16:8 h L:D photoperiod.

Life table analysis

The raw data obtained in the experiments were analyzed based on the age-stage two-sex life table by using the TWOSEX-MS Chart computer program, described by Chi (1988) and developed by Chi & Liu (Chi & Liu, 1985; Chi, 1988, 2013; Huang & Chi, 2011). The variances and standard errors of the population parameters were estimated using the bootstrap technique (Efron & Tibshirani, 1993; Polat Akköprü et al., 2015; Özgökçe et al., 2018) with 200,000 resampling to obtain stable estimates (Akça et al., 2015).

The age-stage specific survival rate (s_{xj}; *x*: age, *j*: period), the age-specific survival rate (l_x), the age-specific fecundity (m_x) and also life table population parameters such as intrinsic rate of increase (*r*), finite rate of increase (λ), net reproductive rate (R_0) and mean generation time (*T*) were calculated.

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

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

where, *k* is the number of stages and s_{xj} is the probability a newly emerged nymph will survive to age *x* and stage *j*.

The intrinsic rate of increase (*r*), Euler-Lotka equation (Goodman, 1982),

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \tag{3}$$

Net reproductive rate (R_0),

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \tag{4}$$

Mean generation time (*T*) is the time required for a population to increase to R_0-fold at stable age-stage distribution,

$$T = \frac{\ln R_0}{r} \tag{5}$$

Finite rate of increase (the rate at which the population increases from one day to the next day) (d^{-1}),

$$\lambda = e^{r} \tag{6}$$

The life expectancy (e_{xj}), which is the time that an individual of age *i* and stage *j* is expected to live, was calculated according to Chi & Su (2006),

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

The reproductive value is defined as the contribution of an individual to the future population (Fisher, 1930). The reproductive value, v_{xj}, was calculated according to Huang and Chi (2011) and Tuan et al. (2014a, b) in age-stage two-sex life table.

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{k} s'_{iy} f_{iy} \tag{8}$$

Population Projection

TIMING-MSChart (Chi, 2014) computer program was used to project the population growth with an initial population of 10 newly emerged nymphs to reveal the growth and age-stage structure of biparental and uniparental forms of oleander scale. The methods developed by Chi & Liu (1985) and Chi (1990).

Results and Discussion

All the biparental and 92% of the uniparental nymphs of oleander scale were able to became adult and generate a new population. The growth, reproduction and survival rates of both forms of the insect and the life table parameters are given in Table 1. According to the comparison tests performed, statistically significant differences were found between the development time, longevity, oviposition period, total pre-oviposition period, fecundity, mean generation time and net reproductive periods of biparental and uniparental forms (Table 1).

Table 1. Life table parameters of biparental and uniparental forms of the oleander scale, *Aspidiotus nerii* at 25±1ºC, 65±1% RH and 16:8 h L:D photoperiod

	Biparental		Uniparental				
	n	Mean±SE	n	Mean±SE	*F*	df	*P*
Development time (d)	191	45.07±0.09	69	59.78±0.42	9743.1	264	0.000*
Adult longevity (d)	191	17.31±1.64	69	28.80±0.42	9982.0	264	0.000*
Mean longevity, female (d)	65	93.29±0.46	69	88.58±0.76	1590.0	132	0.000*
Mean longevity, male (d)	126	46.43±0.14	-	-	-	-	-
Mean longevity, all (d)	191	62.38±1.62	75	84.16±1.91	8796.8	264	0.000*
APOP** (d)	65	12.17±0.08	69	12.06±0.05	84.9	132	0.259
TPOP*** (d)	65	56.74±0.96	69	71.78±0.42	345.9	132	0.000*
Oviposition period (d)	65	18.78±1.09	69	9.45±0.52	4130.4	132	0.000*
Fecundity (nymphs/female)	65	41.34±3.91	69	29.55±1.73	521.4	132	0.006*
Intrinsic rate of increase, (r) (d^{-1})	191	0.039±0.00	75	0.042±0.00	188.3	264	0.173
Finite rate of increase, (λ) (d^{-1})	191	1.040±0.00	75	1.043±0.00	188.6	264	0.173
Mean generation time, (T) (d)	191	67.51±0.43	75	78.49±0.53	9878.3	264	0.000*
Net reproductive rate, (R_0)	191	14.07±1.94	75	27.19±1.83	3142.9	264	0.000*

Standard errors were calculated by using with 200,000 bootstrap replicates. The difference between means in the same row and indicated with * is significant according to $P < 0.05$ (F test; Sidak); ** Adult pre-oviposition period of female adult; *** Total pre-oviposition period of female counted from birth.

Developmental time (45.07 and 59.78 d), adult longevity (17.31 and 28.80 d), mean longevity of all (62.38 and 84.16 d), the generation times (*TPOP*) (56.74 and 71.78 d), and mean generation times (67.51 and 78.49 d) were significantly shorter in the biparental form than the uniparental form, respectively (Table 1). Mean longevity of female (93.29 and 88.58 d) and oviposition periods (18.78 and 9.45 d) were significantly longer in the biparental form than the uniparental form, respectively (Table 1). Similarly, fecundity (41.34, 29.55 nymphs/female) and net reproductive rate (14.07 and 27.19 nymphs) were significantly higher in the biparental form, respectively (Table 1).

Since life table parameters reflect combined effects of life history parameters, including survival, development and reproduction, they provide an accurate estimate of the growth rate of an insect population (Uygun & Atlıhan, 2000; Atlıhan & Özgökçe, 2002; Özgökçe & Atlıhan, 2005; Özgökçe et al., 2006; Atlıhan & Chi, 2008; Chang et al., 2016; Tuan et al., 2016, Atlıhan et al., 2017; Bussaman et al., 2017). In this study, no differences were found between the intrinsic rates of increase (0.039, 0.042 d^{-1}) and the finite rate of increase (1.040, 1.043 d^{-1}) for either form (Table 1).

The age-stage-specific survival rate (s_{xj}) of both forms are represented in Figure 1. These curves show the probability that a newly emerged individual will survive to age x and stage j. For example, the probability that a newly emerged nymph survives to the adult stage is 0.24 for males and 0.34 for females for the biparental form and 0.92 for the uniparental form (Figure 1). Given the variation in the developmental rate between biparental and uniparental forms, there are obvious overlapping of stages.

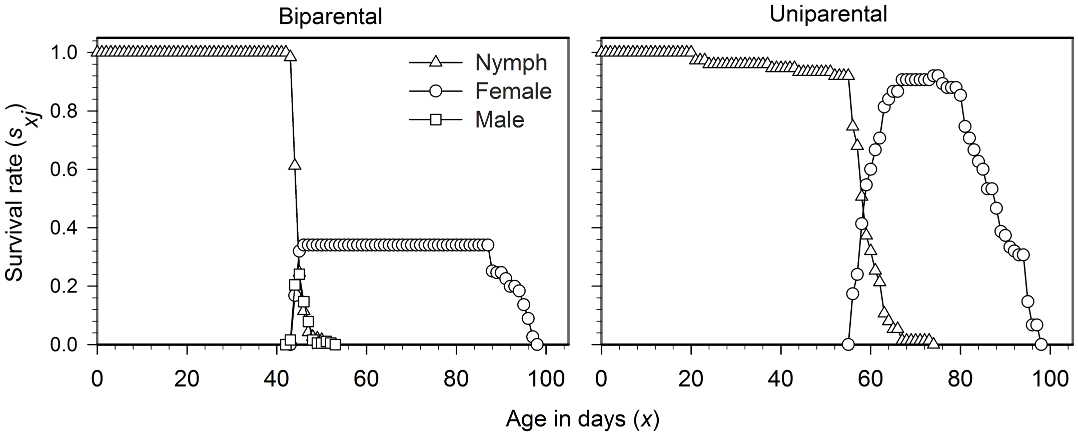

Figure 1. Age-stage specific survival rate (s_{xj}) of biparental and uniparental forms of *Aspidiotus nerii* on squash.

The age-specific survival rate (l_x), the age-specific fecundity (m_x) and the age-specific maternity ($l_x m_x$) curves of both forms of oleander scale are shown in Figure 2. The l_x is the probability that a newly emerged individual survive to x and its curve is a derivate s_{xj} (Marouf et al., 2013). The l_x of the biparental form sharply decreased from 45-52 d due to death of male individuals within 1-2 d and the adult females in the cohort died from 86-98 d. Whereas, the uniparental females died from 75-98 d (Figure 2). While the first reproduction began after 56 d and reached the highest growth rate (3.74 individuals/female) within 6 d in the biparental form, it began after 68 d and reached highest level (3.10 individuals/female) at 87 d in the uniparental form (Figure 2).

The total numbers of nymphs emerging for the whole population were 2687 for biparental and 2039 uniparental forms. Although a shorter developmental period, a longer oviposition period and a higher fecundity was found for the biparental form. The age-specific maternity curve, which was calculated under the effect of sharply decrease in the survival rate at the beginning of the reproduction, showed a gradual departure from the m_x curve in the biparental form (Figure 2).

The expected life time (e_{xj}) of individuals in both forms of the oleander scale is shown in Figure 3 and it estimates the time individuals of age x and stage j are expected to live. For example, the life expectancy of a newly emerged nymph is 62.38 d for the biparental form while it is 84.16 d for the uniparental form. Reproductive value (v_{xj}) for a newly emerged individual is the finite rate of increase (λ) and gives the expectation of future population of individuals of age x and stage j (Fisher, 1930; Pianka, 1994; Kavousi et al., 2009). The peak in reproductive value 27.90 individuals occurred after 57 d in the biparental form, and 19.92 individuals after 68 d in the uniparental form (Figure 4).

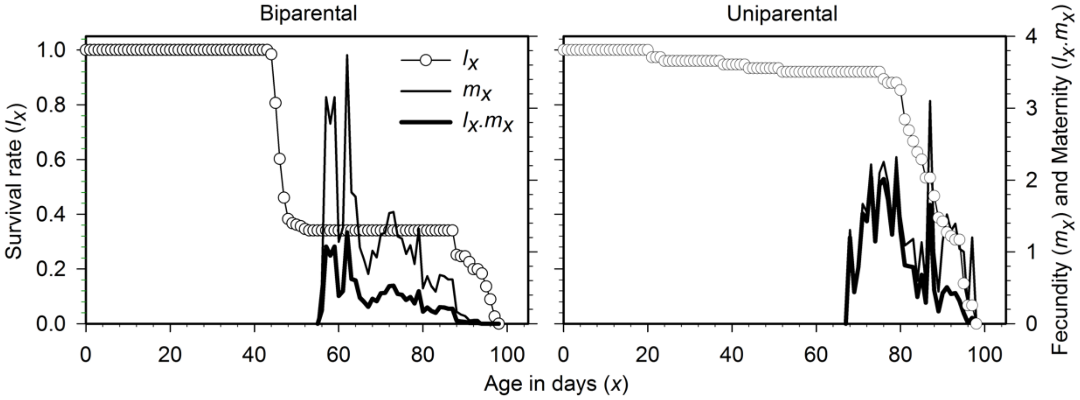

Figure 2. Age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity (l_xm_x) of biparental and uniparental forms of *Aspidiotus nerii* on squash.

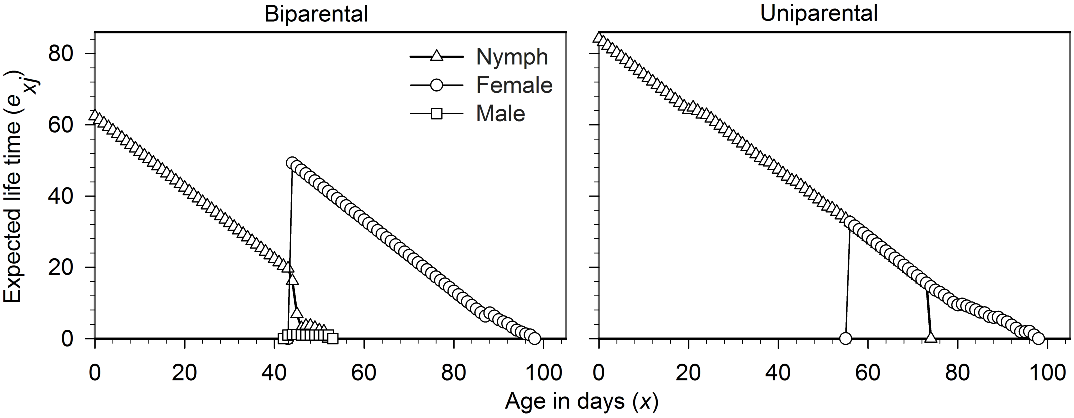

Figure 3. Age-stage-specific life expectancy (e_{xj}) of biparental and uniparental forms of *Aspidiotus nerii* on squash.

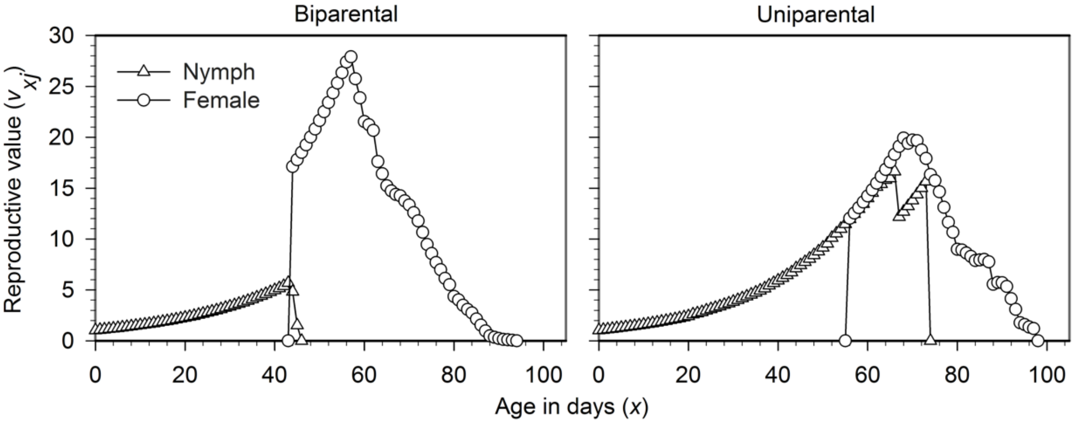

Figure 4. Age-stage-specific reproductive value (v_{xj}) of biparental and uniparental forms of *Aspidiotus nerii* on squash.

The intrinsic rate of increase is most important parameter in life table studies and it gives the most comprehensive description of the growth, development and reproduction of a population, however, it gives no information about the number of individuals. The population projection is an estimate of the future population of a cohort using the basic data (survival rate, development rate and fecundity), and it predicts the growth trends, as well as the stage structure of a population in the short or long term (Farhadi et al., 2011; Huang & Chi, 2011). The population size which a given initial population can reach in a specified time can be estimated by using the TIMING-MSChart program. In this study, 10 newly emerged nymphs were taken as the initial population for the biparental and uniparental forms of oleander scale, and the population size after 100 d according to each stage was calculated and the results are given in Figure 5. Theoretically, it is estimated that the total number of individuals can reach about 140 and 266 individuals, respectively.

Gerson & Hazan (1979) reported that the generation time of the biparental form was shorter than the uniparental form at 19, 24 and 28ºC. They reported that the biparental form completed a generation in about 45 d and the uniparental form in about 64 d at 24ºC, which close to the temperature in this study. Similarly, they emphasized that the number of progeny and oviposition periods were statistically higher for the biparental form at the three temperatures. The same researchers found that the biparental form produced 99.7 nymphs and the uniparental form 41.6 nymphs, and the oviposition periods were 37.2 d and 24.3 d at 24ºC, respectively. Schmutterer (1952) reported that both forms required about 91 d to complete a generation, biparental females each produced an average 127 nymphs and uniparental females 41 nymphs at 25ºC and 80% RH. In a similar study by DeBach & Fisher (1956), the time required for the uniparental form to complete a generation at 23.9ºC was 49 d and the maximum number of nymphs was 94.

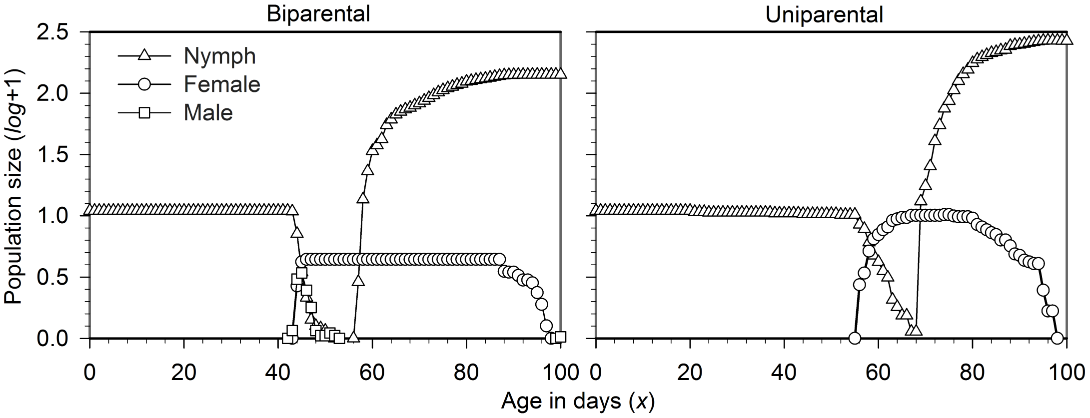

Figure 5. Population projection showing the change of age-stage structure of biparental and uniparental forms of *Aspidiotus nerii* on squash during population growth.

In this study, the biparental form was able to complete a generation in 57 d and the uniparental form in 72 d, and the oviposition periods were about 19 and 9.5 d respectively. During this period, maximum total nymphs were 176 and 67, respectively. Growth conditions and host differences are likely to be the reason for the differences in the results.

However, in previous studies, consistent general results were obtained in terms of development, reproduction and generation times for both forms, that is, the biparental form developed faster, the duration of oviposition was longer, and the number of nymph was greater.

There are some noteworthy differences in the life table results of both forms of the oleander scale. A life table, which is generated based on the development, reproduction, and survival data under certain conditions by an organism, can provide basic information about the entire biology and population dynamics. Among the parameters of a life table, in particular the intrinsic rate of increase is a highly useful parameter for comparing organisms. In this study, although the biparental and uniparental forms of oleander scale have statistically significant differences between the development, reproduction, survival and some of the life table parameters calculated, there were no significant differences between the intrinsic rate of increase and the finite rate of increase. However, the net reproductive rate and mean generation time parameters were statistically different between the both forms. As found in this study and also in previous studies, the number of nymphs of the biparental form was significantly higher than the uniparental form. The biparental form was found to give 2.6 times more nymphs than the uniparental form in terms of total number of nymphs and net reproductive rate even though the mean generation time was shorter. When the life table parameters are calculated, the sex ratios as well as the rate of reproduction, development and survival ratios are taken into account. The sex ratio in the biparental population was 66% males. These differences may cause significant changes in population dynamics in favor of the uniparental form over the long term. Specifically, according to the population projection, the uniparental form was found to increase the population by 1.9 times compared to the biparental form based on a 100-d estimate. In the comparison of the life table parameters, r and λ are statistically different, while T is shorter in favor of the biparental form, and R_0 is greater in favor of the uniparental form. Therefore, it is difficult to conclude which form has the more advantageous population dynamics. The population projections obtained in this study are important as they provide a more detailed understanding on this pest.

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