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Research Article

Life Table of *Spodoptera exigua* (Lepidoptera: Noctuidae) on Five Soybean Cultivars

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Effect of five soybean cultivars (Sahar, JK, BP, Williams, and L17) on life table parameters of the beet armyworm *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) was evaluated at $25 \pm 1^{\circ}$C, 60 ± 5% relative humidity and a photoperiod of 16 h light/8 h dark. The highest and lowest net fecundity rates were obtained on Williams (244.1 ± 19.4 eggs/female) and L17 (80.5 ± 6.9 eggs/female), respectively. The net reproductive rates (R_o) were highest on Williams (137.0 ± 11.2 females/female/generation) and lowest on BP (41.3 ± 4.1 females/female/generation). The intrinsic rate of increase (r_m) differed significantly among five soybean cultivars, ranging from 0.1169 day^{-1} (on Williams) to 0.122 day^{-1} (on BP). The highest value of finite rate of increase (λ) was on Williams (1.18 day^{-1}), which was significantly different from other cultivars. The mean generation time (T_c) was significantly different on various cultivars, ranging from 32.0 ± 0.3 days (on L17) to 28.8 ± 0.3 days (on Sahar). The results are discussed with respect to the potential effect of soybean cultivars on the performance of *S. exigua*.

1. Introduction

Soybean (*Glycine max* (L.) Merrill) is an economically important crop and commercially produced in the northern region of Iran [1]. The beet armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera : Noctuidae) is native to Asia but has been introduced worldwide and is now found almost anywhere its many host crops are grown. It is an important pest of soybean in Iran [2] and some parts of the world [3, 4]. It is one of the most common and destructive insect pests of more than 90 plant species in at least 18 families around the world [3, 5, 6]. The wide host range of the beet armyworm includes soybean, sugar beet, cabbage, cauliflower, brussel sprouts, tomato, maize, cotton, lettuce, peanut, alfalfa, shallot, pastures crops, and various wild hosts [3]. The intensive use of insecticides for control of this pest has resulted in high levels of resistance to virtually all commercial insecticides in many parts of the world [4, 7]. Host plant resistance is one way of controlling insects that is not detrimental to the environment and also reduces expenses for growers [8]. Identification of host plant resistance mechanisms can enable proper selection of resistant genotypes that can be used in plants breeding programs [9]. In recent years, the beet armyworm has become a serious pest on soybean in some parts of Iran. Therefore, the objective of this research was to examine the effect of different soybean cultivars on the life table of *S. exigua*, which is useful for its management and potential soybean breeding for resistance.

Life table parameters are important in the measurement of population growth capacity of species under specified conditions. These parameters are also used as indices of population growth rates responding to selected conditions and as bioclimatic indices in assessing the potential of a pest population growth in a new area [10]. Fertility life tables are appropriate to study the dynamics of animal populations, especially arthropods, as an intermediate process for estimating parameters related to the population growth potential, also called demographic parameters [11]. This information could be extremely valuable for the future development of IPM programs against *S. exigua*. Life table studies have several applications including analyzing population stability and structure, estimating extinction probabilities, predicting life history evolution, predicting outbreak in pest species, and examining the dynamics of colonizing or invading species [12, 13]. Life table information may also be useful in constructing population models [14, 15] and understanding interactions with other insect pests and natural enemies [16].

The intrinsic rate of increase (r_m) is a key demographic parameter useful for predicting the population growth potential of an animal under a given environmental condition [10, 17, 18]. Under non limiting environmental conditions and with a stable age distribution, this parameter will be characterized by a constant population size. The r_m-value can be estimated from life table data under standardized laboratory condition. The r_m-value is the rate of growth of a population when that population is growing under ideal conditions and without limits [10]. A number of extrinsic and intrinsic factors have been shown to affect the r_m-value and related demographic parameters. These include temperature, geographical origin of insect, and host plant cultivars [19–21].

The life history and population growth parameters of *S. exigua* have been studied on different host plants by Greenberg et al. [22], who reported that the performance of *S. exigua* was best on pigweed, worst on cabbage, and intermediate on cotton, pepper, and sunflower. Realized and potential fecundity and egg fertility of *S. exigua* under different adult diet regimes have been studied by Tisdale and Sappington [7]. Several studies have dealt with beet armyworm fecundity and growth potential, and some of the environmental factors that may influence them [23–28]. However, there is no information related to performance of this pest on different soybean cultivars. The current study is designed to evaluate the effectiveness of five soybean cultivars on the demographic parameters of the *S. exigua*. These five cultivars are covering the most area of soybean growing in Iran and some other parts of the world [29]. Knowledge of life table parameters of *S. exigua* and resistance susceptibility of different soybean cultivar may be necessary to select the most suitable cultivar or employ the appropriate control tactics and integrated crop management (ICM) for particular soybean cultivars.

2. Materials and Methods

2.1. Rearing Methods and Experimental Conditions. Seeds of the five soybean cultivars including Sahar, JK, BP, Williams, and L17 were obtained from the Plant and Seed Modification Research Institute (Karaj, Iran) and were sown in the research field of Tarbiat Modares University in suburbs of Tehran, Iran in May 2008. For this study, the leaves of different soybean cultivars were transferred to a growth chamber at $25 \pm 1°C$, $60 \pm 5\%$ RH and a photoperiod of 16 : 8 (L : D) hours and used for feeding of different larval stages of *S. exigua*.

Larvae and pupae of *S. exigua* were originally collected from sugar beet fields in Ghafar Behi village in West Azerbaijan, Iran (45°09′35′′E and 37°31′49′′N). The cultures were reared on each soybean cultivar for one generation in a growth chamber at the same conditions as above before using them in the experiments. The colony was supplemented, from time to time, with larvae collected from field to prevent any inbreeding effects.

2.2. Survival Rate and Mortality. The newly emerged adults were transferred to cages (14 cm diameter, 19 cm height) for mating. This cage was a clear and cubic Plexiglas container. A piece of wax paper was inserted in the container on which the females lay their eggs. After 12 h, the laid eggs were collected from the container and were used in the experiments. In total, 219, 200, 225, 176, and 230 eggs of *S. exigua* were used to collect data on Sahar, JK, BP, Williams, and L17 soybean cultivars, respectively. In order to calculate age-specific survival rate and daily fecundity of *S. exigua*, each egg was placed individually into plastic Petri dishes (8.5 cm diameter and 3 cm height) containing fresh leaves of different examined soybean cultivars. A hole (3 cm diameter) was cut at the centre of top of Petri dishes and covered by fine nylon mesh for ventilation. Larval instars were determined by the presence of newly molted exuviae and head capsules. Developmental stages were checked daily and developmental periods and mortality of eggs, larvae, pupae, and adults were recorded. The experiment was continued until the death of all individual members of each cohort.

2.3. Reproduction and Population Growth Parameters. In order to calculate reproduction and population parameters of *S. exigua*, a pair of newly emerged female and male adult moths (with 25 replications on each soybean cultivar) were introduced into each clear plastic container (11 cm diameter, 12 cm height), which was closed at the top with fine nylon mesh for ventilation. A small cotton wick soaked in 10% honey solution was placed in the oviposition containers to provide a source of carbohydrate for adult feeding. The number of eggs laid by each female was recorded daily until the last female died. To obtain sex ratio on each host plant cultivars, deposited eggs produced on each soybean cultivar were maintained until adult moths emerged, and sex ratio of emerged adults was determined.

2.4. Data Analysis. Life span differences among cohorts on various soybean cultivars were analyzed by Kolmogorov-Smirnov test [30]. The reproduction parameters for *S. exigua* including gross fecundity rate and gross fertility rate (the total number of eggs and hatching eggs by an average female that lives to the last day of possible life in the cohort, resp.), net fecundity rate and net fertility rate (the average lifetime production of eggs and fertile eggs for a newborn female, resp.), gross hatch rate (the ratio of gross fertility to gross fecundity), daily eggs laid per female, and daily fertile eggs laid per female on different cultivars were estimated using formulae suggested by Carey [14, 15].

The age-specific survival rate, daily fecundity, and sex ratio were used to construct $l_x m_x$ life tables from which the following population growth parameters were calculated using formula suggested by Carey [14, 15]: intrinsic rate of increase (r_m), mean generation time (T_c), finite rate of increase (λ), net reproduction rate (R_o), and doubling time (DT). Age-specific survival rates (l_x) and average number of female eggs per day (m_x) for each age interval (x) were used to construct age-specific fertility life tables. For example, the intrinsic rate of increase (r_m) of *S. exigua* on different cultivars was estimated using the following:

$$\sum_{x=\alpha}^{\beta} e^{-r_m x} l_x m_x = 1. \quad (1)$$

The Jackknife procedure was used to estimate the variance for r_m and the other population parameters [31]. The Jackknife method removes one observation from the original data set and recalculates the statistic of interest from the truncated data set. These new estimates, or pseudovalues, form a set of numbers from which mean values and variances can be calculated and compared statistically [11]. The steps for the application of the method are the following.

The r_m value was estimated by considering the survival and reproduction data for all the n females, referred to as true calculation ($r_{m(\text{all})}$). Then this procedure was repeated for n times, each time excluding a different female. In so doing, in each time, data of $n-1$ females were taken to estimate parameters ($r_{m(i)}$). In the following step, pseudo values of r_m(psv $r_{m(i)}$) were calculated for the n samples using the following equation:

$$\text{psv}\, r_{m(i)} = n \times r_{m(\text{all})} - (n-1) \times r_{m(i)}. \quad (2)$$

After calculating all the n pseudo-values for r_m, Jackknife estimate of the mean ($r_{m(J)}$), variance, and standard error is calculated, respectively, by the following:

$$r_{m(J)} = \frac{\sum_{i=1}^{n} \text{psv}\, r_{m(i)}}{n},$$

$$\text{var}\left(r_{m(J)}\right) = \frac{\sum_{i=1}^{n}\left(\text{psv}\, r_{m(i)} - r_{m(J)}\right)^2}{n-1}, \quad (3)$$

$$\text{SE}\left(r_{m(J)}\right) = \sqrt{\frac{\text{var}\left(r_{m(J)}\right)}{n}}.$$

The mean values of n jackknife pseudo values for each soybean cultivar were subjected to one-way ANOVA.

The similar procedures were used for the other parameters (R_o, λ, T, and DT). Effect of host plant cultivars on different parameters was analyzed using one-way ANOVA. If significant differences were detected, multiple comparisons were made using the Student-Newman-Keuls (SNK) ($P < 0.01$). Statistical analysis was carried out using Minitab ver.13.1 software [32].

3. Results and Discussion

3.1. Survival Rate and Fecundity. Age-specific survival rate (l_x) and fecundity (m_x) of *S. exigua* on different soybean cultivars are shown in Figure 1. Survivorship curves of *S. exigua* on all soybean cultivars were type III. In this type of survivorship, most of the mortality occurs early in the life (e.g., egg stage) [33]. The survival rate to the first day of adult emergence was 19.6, 37.5, 16.5, 21.9, and 24.5% on BP, Williams, L17, Sahar, and JK, respectively. The results indicated that the death of the last female (maximum age) occurred in the age of 39.2, 42.9, 43.3, 38.3, and 40.5 days for males and in the age of 45.1, 46.2, 46.3, 39.8, and 41.0 days for females on BP, Williams, L17, Sahar, and JK, respectively.

The mated females began oviposition 5-6 days after emergence. The females began to lay eggs in the age of 30.5, 28.5, 32.5, 30.5, and 30.5 days on BP, Williams, L17, Sahar, and JK cultivars, respectively. The highest daily fecundity (m_x) of *S. exigua* adults emerged from larvae reared on these cultivars was 37.5, 56.8, 44.3, 62.1, and 33.3 eggs/female/day occurred in the age of 33.5, 31.5, 40.5, 32.5, and 34.5 days, respectively (Figure 1). The lifespan of females of *S. exigua* was significantly longer on Williams and JK in comparison to other cultivars ($P < 0.05$). However, no significant difference was observed between lifespan of males on soybean cultivars (Table 1).

3.2. Reproduction Parameters. The results of the reproduction parameters of *S. exigua* are given in Table 2. The gross hatch rate of *S. exigua* ranged from 26% on L17 to 37.5% on Williams. The gross and net fecundity rates significantly differed on various soybean cultivars ($F = 4.55$; df = 4,108; $P < 0.01$ and $F = 28.40$; df = 4,105; $P < 0.01$). The highest rates of gross and net fecundity were obtained on Williams. However, there was no significant difference between gross and net fecundity rates on other soybean cultivars. Among different soybean cultivars, the gross fertility rate was the highest on Williams. The net fertility rate varied from 21.0 to 102.5 eggs, which was significantly higher on Williams compared to the other cultivars. Both daily number of eggs and daily number of fertile eggs laid per female were significantly higher on Sahar than L17, Jk, and BP, but there was no significant difference between Sahar and Williams cultivars (Table 2).

3.3. Population Growth Parameters. The population growth parameters of *S. exigua* on five soybean cultivars are given in Table 3. There were significant differences between the net reproductive rates (R_o) on five soybean cultivars (F = 34.412; df = 4,103; $P < 0.01$). The highest value of R_o was on Williams. However, no significant difference was observed between R_o-values on other soybean cultivars. The intrinsic rates of increase (r_m) were also found to be significant on different cultivars ($F = 8.991$; df = 4,103; $P < 0.01$). The r_m-value ranged from 0.1169 to 0.1680, which was the highest on Williams. The highest value of finite rate of increase (λ) was obtained on Williams, which was significantly different from other cultivars ($F = 23.342$; df = 4,103; $P < 0.01$). The doubling time (DT) was not found to be significantly different on various soybean cultivars ($F = 1.296$; df = 4,103; $P > 0.05$) (Table 3). But, the mean generation time (T_c) was significantly different on host plant cultivars ($F = 10.443$; df = 4,103; $P < 0.01$), which showed longer generation time on L17 compared to the other cultivars (Table 3).

The reproduction and population growth parameters of *S. exigua* vary considerably depending on various factors such as host plants and environmental conditions [7, 22].

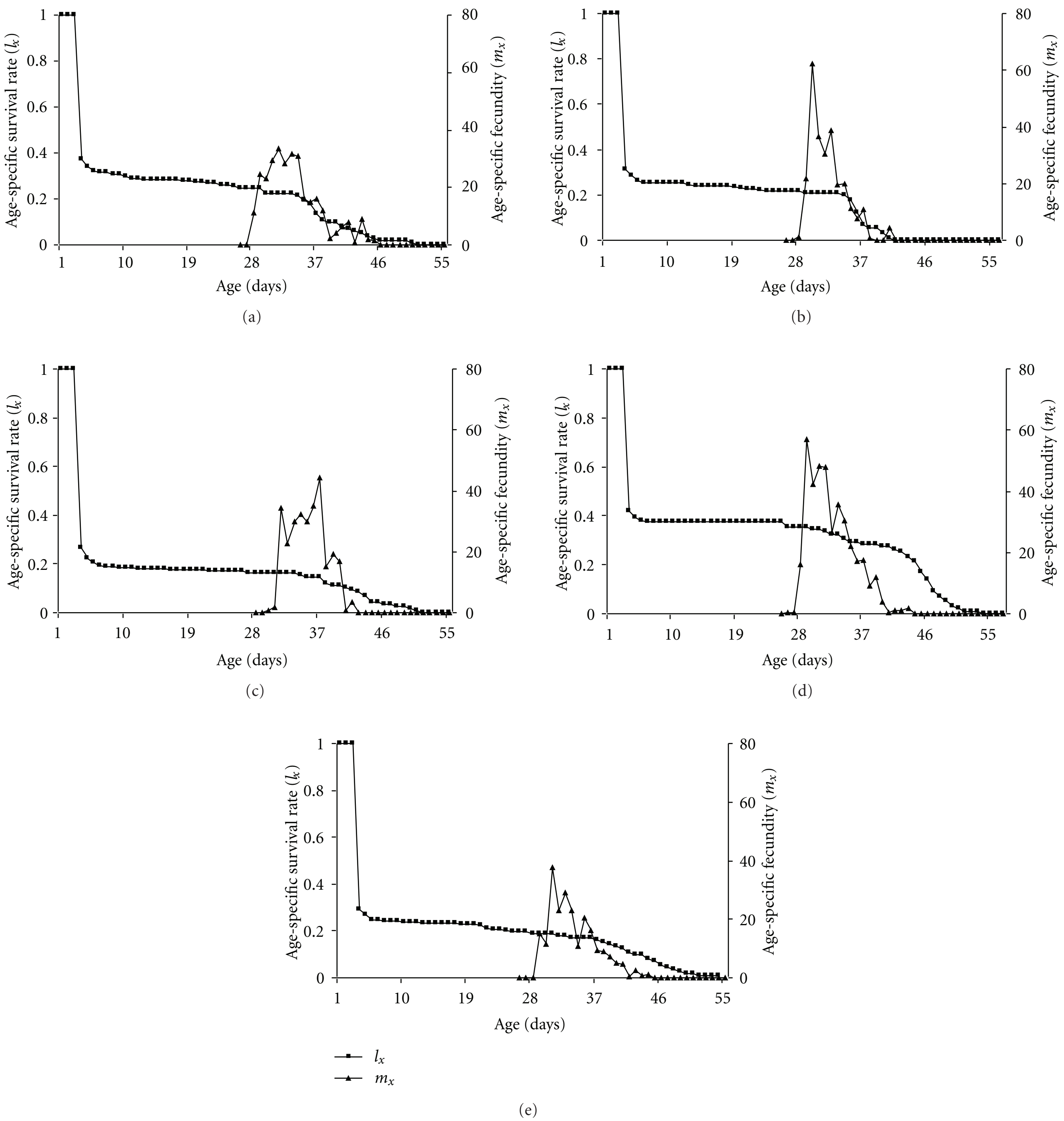

Figure 1: Age-specific survivorship (l_x) and age-specific fecundity (m_x) of beet armyworm *Spodoptera exigua* on various soybean cultivars, (a) JK, (b) Sahar, (c) L17, (d) Williams, and (e) BP.

The present study demonstrated that the performance of *S. exigua* significantly differed on the five soybean cultivars tested. In regard to insect-plant interactions, it is useful to determine the effect of the different cultivars on the performance of herbivores. Understanding the life table parameters of *S. Exigua* is one of the essential components in developing an integrated pest management program for soybean in Iran. No other study has covered the effect of various soybean cultivars on survival and reproduction of the *S. exigua* in Iran.

Differences in the number of eggs per female (gross fecundity rate) among soybean cultivars were found to be significant. Sethi et al. [28] reported that fecundity of *S. exigua* for Valmaine and Tall Guzmaine cultivars of lettuce was 123.2 and 383.6 eggs, respectively, which was lower than those obtained in the current study. The difference between

Table 1: Comparison of lifespan of *Spodoptera exigua* on five soybean cultivars using the Kolmogorov-Smirnov test.

Soybean cultivars	Lifespan (Days) Female (mean ± SE)	Female range	Male (mean ± SE)	Male range
JK	9.93 ± 1.08^{ab}	3–56	9.46 ± 1.01^{a}	3–51
Sahar	7.70 ± 0.84^{b}	3–45	7.86 ± 0.83^{a}	3–43
L17	7.64 ± 0.88^{b}	3–56	7.20 ± 0.81^{a}	3–50
Williams	14.29 ± 1.58^{a}	3–59	11.377 ± 1.4^{a}	3–64
BP	8.54 ± 0.97^{b}	3–60	8.06 ± 0.86^{a}	3–56

Means followed by the same letters in a column are not significantly different ($P < 0.05$).

Table 2: The reproduction parameters (Mean ± SEM) of the beet armyworm *Spodoptera exigua* on five soybean cultivars.

Parameters	Soybean cultivars JK	Sahar	L17	Williams	BP
Gross fecundity rate	549.0 ± 79.8^{b}	558.3 ± 57.9^{b}	555 ± 44.4^{b}	771.3 ± 49.2^{a}	462.9 ± 34.8^{b}
Gross fertility rate	203.6 ± 29.6^{b}	202.1 ± 32.5^{b}	144.5 ± 11.6^{b}	292.4 ± 20.7^{a}	134.2 ± 10.1^{b}
Net fecundity rate	114.9 ± 12.5^{b}	96.1 ± 12.5^{b}	80.5 ± 6.9^{b}	244.1 ± 19.4^{a}	84.0 ± 8.5^{b}
Net fertility rate	42.6 ± 4.7^{b}	29.7 ± 17.0^{bc}	21.0 ± 1.8^{c}	102.5 ± 8.2^{a}	24.4 ± 2.5^{c}
Mean egg per day	20.3 ± 2.9^{bc}	31.0 ± 3.2^{a}	21.4 ± 1.7^{bc}	24.9 ± 1.6^{ab}	14.9 ± 1.1^{c}
Mean fertile egg per day	7.5 ± 1.1^{bc}	11.2 ± 1.8^{a}	5.6 ± 0.5^{c}	9.4 ± 0.7^{ab}	4.3 ± 0.3^{c}

Means followed by the same letters in a row are not significantly different ($P < 0.01$).

Table 3: The population growth parameters (Mean ± SEM) of the beet armyworm *Spodoptera exigua* on five soybean cultivars.

Parameters	Soybean cultivars JK	Sahar	L17	Williams	BP
Net reproductive rate (R_o)	59.0 ± 6.4^{b}	44.4 ± 6.2^{b}	42.0 ± 3.6^{b}	137.0 ± 11.2^{a}	41.3 ± 4.1^{b}
Intrinsic rate of increase (r_m)	0.137 ± 0.004^{ab}	0.132 ± 0.006^{bc}	0.117 ± 0.003^{c}	0.168 ± 0.004^{a}	0.122 ± 0.004^{c}
Finite rate of increase (λ)	1.15 ± 0.005^{b}	1.14 ± 0.006^{bc}	1.12 ± 0.003^{d}	1.18 ± 0.005^{a}	1.13 ± 0.004^{cd}
Doubling time (DT)	5.0 ± 0.2^{a}	5.2 ± 0.2^{a}	5.9 ± 0.1^{a}	4.1 ± 0.1^{a}	5.7 ± 0.2^{a}
Mean generation time (T)	29.7 ± 0.5^{bc}	28.8 ± 0.3^{c}	32.0 ± 0.3^{a}	29.3 ± 0.3^{bc}	30.4 ± 0.4^{b}

Means followed by the same letters in a row are not significantly different ($P < 0.01$).

our study and results of Sethi et al. [28] could be resulted of host plant differences.

The higher intrinsic rate of increase (r_m) on Williams were resulted from faster development (shorter generation time), higher survivorship, and higher fecundity rates. High value of r_m indicates the susceptibility of a host plant to insect feeding, while a low value indicates that the host plant species is somewhat resistant or tolerant to the pest. Therefore, our data showed the tremendous growth capacity of *S. exigua* under favorable conditions. Greenberg et al. [22] investigated the life table parameter of this pest on different host plants and observed that the r_m value was the highest on pigweed (0.264) and lowest on cabbage (0.156). Some possible reasons for disagreement are due to physiological differences depending on the type of the host plant cultivar, genetic differences as a result of laboratory rearing or variation in geographic populations of the pest. Furthermore, our findings led us to consider soybean as a poorer-quality host for *S. exigua* than those tested by Greenberg et al. [22].

Our finding indicated that the highest value of net reproductive rate of *S. exigua* was obtained on Williams. Greenberg et al. [22] reported that net reproductive rate of the *S. exigua* ranged from 139.3 to 596.0 on cabbage and pigweed, respectively. Therefore, according to our results, the net reproductive rate of *S. exigua* on Williams was nearly similar to cabbage. The longest generation time (T_c) was obtained on L17 (32.0 ± 0.3 days), and the shortest was on Sahar (28.8 ± 0.3 days). According to the results of Greenberg et al. [22], the mean generation time of the *S. exigua* was longest on cabbage (31.6 days) and shortest on pigweed (24.2 days) on cabbage which was nearly similar to our estimated generation time on L17 soybean cultivar. Naseri et al. [34] investigated the reproductive performance of *Helicoverpa armigera* (Hübner) (Lepidoptera : Noctuidae) reared on thirteen soybean varieties and observed that Williams variety was more suitable, and other varieties (BP, Sahar, JK, DPX, and Gorgan3) showed less suitability as host plants for *H. armigera* reproduction which was nearly similar to our results.

There are many factors affecting host suitability, including nutrient content and secondary substances of the host and the capability of digestion and assimilation by an insect [8, 9, 22, 28]. For a better understanding of the insect-plant interaction, basic biochemical studies for the isolation and identification of phytochemicals, which adversly affect the buildup of *S. exigua* population on soybean, are required. Through this research, we may be able to determine the population dynamics of the pest on different host cultivars and use the information to manage the pest population below the economic injury level.

In conclusion, knowledge of the influences of soybean cultivar quality on the life table parameters of the *S. exigua* can help us to understand the population dynamics and management of this insect. The results of the comparison of reproduction and population growths parameters of *S. exigua* on five soybean cultivars revealed that Williams was the most suitable and L17 and BP were the partially resistant cultivars. After laboratory studies, more attention should be devoted to semifiled and field experiments to obtain more applicable results in field conditions.

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