Reproductive performance and growth indices of the cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae) on various host plants

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Abstract: The effect of various host plants including chickpea (varieties Arman, Hashem, Azad and Bivanij), common bean (variety Khomein), white kidney bean (var. Dehghan), red kidney bean (var. Goli), cowpea (variety Mashhad), and tomato (var. Meshkin) on the reproductive performance and growth indices of the cotton bollworm, *Helicoverpa armigera* (Hübner) was determined under laboratory conditions (25 ± 1 °C, 65 ± 5% RH and a 16:8 h light: dark photoperiod). The highest rate of gross fecundity, gross fertility, net fecundity, net fertility, mean daily eggs and mean daily fertile eggs were observed on chickpea Arman (2947.8 ± 7.8, 2933.0 ± 7.8, 2404.2 ± 7.1, 2392.2 ± 7.1, 170.9 ± 0.4, and 170.1 ± 0.4 eggs female^{-1}, respectively), whereas the lowest values of these parameters were on tomato Meshkin (847.5 ± 9.2, 673.8 ± 7.3, 225.5 ± 2.6, 179.3 ± 2.1, 67.9 ± 0.7 and 54.3 ± 0.5 eggs female^{-1}, respectively). The development index of overall immature stages varied from 1.10 to 1.57, with the minimum on tomato Meshkin and the maximum on chickpea Arman. Also, the fitness and standardized insect-growth indices were highest (0.349 ± 0.009 and 0.058 ± 0.001 gr day^{-1}) and lowest (0.052 ± 0.001 and 0.013 ± 0.000 gr day^{-1}) on chickpea Arman and tomato Meshkin, respectively. The Weibull model sufficiently described the shape of the survivorship curve of adult *H. armigera* from life-table data. A significant fit was obtained with the Weibull model for *H. armigera* in all experimental host plants. The results of reproductive performance, growth indices and the cluster analysis showed that tomato Meshkin was partially resistant to *H. armigera*.

Keywords: The cotton bollworm, reproductive parameters, growth indices, host plant

Introduction

In many countries, the cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a polyphagous and economically key pest of various crops. This species infests different crops including cotton, chickpea, tomato, tobacco, corn, sesame, hemp, sunflower, peanut, okra, soybean and bean (Fitt, 1989; Smith, 1992; Naseri *et al.,* 2010; Hemati *et al.,* 2012a). At different development stages, the larvae of *H. armigera* feed on vegetative and reproductive structures of host plants, such as stem, leaf, flower and fruit (Moral Garcia, 2006). The preference of *H. armigera* to feed on the reproductive organs of host crops, along with its high polyphagy and mobility, broad geographical distribution, migratory potential,

facultative diapause, high reproductive performance, and tendency to develop resistance to many chemical pesticides has lead to its status as an important crop pest (Fitt, 1989; Anonymous, 2000).

The fitness of plant-feeding insects depends upon the nutritious substances in the host plant (Du *et al.,* 2004). It is obvious that chemical and nutritional features of the food substrate determine consumption, development and survival in the larval stages of *H. armigera* and egg production of the resulting adults (Singh and Mullick, 1997). Plants with antibiosis mechanism may decrease directly insect survival, size or weight, longevity, and fecundity of adults, or they may have an indirect effect by increasing the exposure of the insect to its natural enemies due to prolonged developmental period (Sarfraz *et al.,* 2006).

Host plant resistance among crop plants is a major part of integrated pest management (IPM). It is relatively constant, cheap, non–polluting, and is compatible with other methods of pest control. Developing resistant cultivars to *H. armigera* would supply an effective complementary approach in IPM to reduce the extent of losses caused by this pest (Sachan, 1990; Jallow *et al.,* 2004).

In spite of the economic importance of *H. armigera*, there is little available information regarding the reproductive performance and growth indices of this pest on various host plants; however, some related studies have been performed on the effect of host plants apart from those tested in our research on reproductive performance and growth indices of *H. armigera*. Here we provide new information on the effects of various host plants as larval food on the reproduction parameters of adult *H. armigera*.

Dhandapani and Balasubramanian (1980) studied the development and reproduction of *H. armigera* on different food plants including cotton, pigeon pea and soybean. The effect of egg load on the host selection behaviour of *H. armigera* was determined under laboratory conditions (Jallow and Zalucki, 1998). Host selection behavior and reproductive performance of Japanese *H. armigera* on an artificial diet and different crops including okra, tomato, eggplant, pepper and maize were studied by Jallow *et al.,* (2001), who reported that the highest fecundity per female was on the artificial diet and the lowest one was on maize. Relationship between oviposition preference and offspring performance in Australian *H. armigera* was studied by Jallow and Zalucki (2003). The effect of six different host plants on the fecundity of *H. armigera* females was determined by Liu *et al.,* (2004) under laboratory conditions. They suggested that females emerging from the larvae that fed on common bean laid more eggs than the larvae reared on other host plants examined. Moreover, studies by Soleimannejad *et al.,* (2010) on demographic parameters of *H. armigera* on seeds of different soybean cultivars, revealed that Sahar, L17, Gorgan3 and M4 cultivars were resistant to *H. armigera*. Also, research on reproductive parameters of *H. armigera* on different soybean varieties by Naseri *et al.,* (2011) showed that varieties JK, Sahar and Gorgan 3 were partially resistant to *H. armigera*.

Hemati *et al.,* (2012a, b, c, d) studied nutritional indices, digestive proteolytic and amylolytic activities, life history and population growth parameters of *H. armigera* on different host plants. Here we complement these works, by studying the effects of various host plants on the reproductive performance and growth indices of *H. armigera* as two important factors determining the susceptibility of the tested host plants to this pest. The results of this study, along with the findings of previous researches on demographic and reproductive parameters of this pest under field conditions, could allow for the creation of a comprehensive plan for an integrated pest management program of *H. armigera* on various host plants.

Materials and Methods

Plants
Seeds of various host plants including chickpea (*Cicer arietinum* L.) (varis. Arman, Hashem,

Azad and Bivanij), common bean (*Phaseolus vulgaris* L.) (var. Khomein), white kidney bean (*P. vulgaris*) (var. Dehghan), red kidney bean (*P. vulgaris*) (var. Goli), cowpea (*Vigna sinensis* L.) (var. Mashhad) and tomato (*Lycopersicon esculentum* Mill) (var. Meshkin) were provided by the Seed and Plant Improvement Institute, Karaj, Iran. They were planted in the research field of the University of Mohaghegh Ardabili located in Ardabil, Iran in May 2010. The experiments were started when each host plant reached its reproductive stage (the same size immature green pod for chickpea and beans and the same size immature green fruit for tomato) in early July 2010. For this research, the leaves, pods and fruits of various host plants were transferred to a growth chamber at 25 ± 1 °C, 65 ± 5% RH, with a photoperiod of 16: 8h (L: D). The leaves of different hosts were used for feeding of first and second larval instars and the green pods (chickpea, common bean, white kidney bean, red kidney bean and cowpea) and fruit (tomato) were used for feeding of the third to fifth larval instars, as reported by Green *et al.,* (2002) and Naseri *et al.,* (2009a, b).

Laboratory insect colony
H. armigera larvae used in the experiments were obtained from a laboratory colony maintained on a defined cowpea-based artificial diet from Department of Plant Protection (Tabriz University, Iran). The artificial diet contained: powdered cowpea seed (250 g), wheat germ (30 g), yeast (35 g), sorbic acid (1.1 g), ascorbic acid (3.5 g), sunflower oil (5 ml), agar (14 g), methyl-p-hydroxy benzoate (2.2 g), formaldehyde 37% (2.5 ml) and distilled water (650 ml) (Shorey and Hale, 1965). Stock culture was initiated on various host plants in a growth chamber (25 ± 1 °C, 65 ± 5% RH and a photoperiod of 16:8h L: D).

Experiments
In order to determine the reproductive parameters of *H. armigera* on various host plants, the emerged adult moths from the larvae fed on these hosts were used in the experiments.

Reproductive parameters of *H. armigera* were studied using the same aged eggs laid within 12 h by females reared as larvae on various host plants. The number of eggs used to begin the experiment on each host plant was 50 eggs. After egg hatching, neonate larvae were transferred individually into plastic plate (diameter 8 cm, depth 1 cm) with a hole covered by a fine mesh net for aeration. These plates contained fresh detached leaves of various host plants for feeding of the first and second instar larvae. The petioles of the detached leaves were inserted in water-soaked cotton to maintain their freshness. The third to fifth instars were fed on pods (chickpea, common bean, white kidney bean, red kidney bean and cowpea) or fruits (tomato) until pre-pupation. The larvae in each plate were checked daily for the mortality or ecdysis. Head capsules or exuviae from moulting larvae were used to distinguish the larval instars. For pre–pupation and pupation, last instar larvae were kept in small plastic tubes (diameter 2 cm, depth 5 cm). Duration of pre-pupal and pupal stages and their mortality were recorded daily.

After emergence of adults from the pupae, a pair of female and male were transferred to each plastic oviposition container (diameter 11 cm, depth 12 cm), which was closed at the top with a fine mesh net for ventilation. The host plant leaves (oviposition substrate) were replaced with new ones every day and number of eggs laid by individual females was recorded daily. For this purpose, the male and female moths were placed in a new oviposition container, then all deposited eggs on a host plant leaf and inner walls of container were counted daily. A small cotton wick soaked in 10% honey solution was placed in the containers to provide a source of carbohydrate for adult feeding. The number of eggs laid by *H. armigera* was recorded until the death of the last female of the cohort. The number of pairs of both sexes of moth tested for each host plant depended on survival from the previous stages and ranged from 15-24 couples.

The reproduction parameters calculated for *H. armigera* from the daily egg counts were:

gross fecundity rate (GFR), gross fertility rate (GFrR), gross hatch rate (GHR), net fecundity rate (NFR), net fertility rate (NFrR), daily eggs laid per female and daily fertile eggs laid per female (Carey, 1993):

$$\text{Gross fecundity rate} = \sum_{\alpha}^{\beta} M_x$$

$$\text{Gross fertility rate} = \sum_{x=\alpha}^{\beta} h_x M_x$$

$$\text{Gross hatch rate} = \frac{\sum_{x=\alpha}^{\beta} h_x M_x}{\sum_{x=\alpha}^{\beta} M_x}$$

$$\text{Net fecundity rate} = \sum_{x=\alpha}^{\beta} L_x M_x$$

$$\text{Net fertility rate} = \sum_{x=\alpha}^{\beta} L_x h_x M_x$$

$$\text{Daily eggs laid per female} = \frac{\sum_{x=\alpha}^{\beta} M_x}{(\varepsilon - \omega)}$$

Daily fertile eggs laid per female= $\frac{\sum_{x=\alpha}^{\beta} h_x M_x}{(\varepsilon - \omega)}$ where, L_x is the days lived in interval x and $x+1$, M_x is the average number of offsprings produced by females at age x and h_x is the hatching rate; α is the age of female at the first oviposition and β is the age of female at the last oviposition and $\varepsilon - \omega$ is the female longevity.

In order to estimate the growth indices, every pupa was weighed 24 hours after pupation. In this study, the larval, pre-pupal, pupal and overall immature growth indices (GI), standardized insect-growth index (SII) and fitness index (FI) of *H. armigera* was calculated on various host plants using the following formulae (Pretorius 1976; Itoyama *et al.,* 1999):

GI = l_x/T

SII = Pw/L

FI = (P × Pw)/(L + Pd)

where, l_x = survival rate of each immature stage, T = period of each immature stage, L = larval period, P = percentage of pupation, Pd = pupal period and Pw = pupal weight.

Data analysis
Reproductive parameters and growth indices of *H. armigera* reared on various host plants were analyzed with one-way ANOVA using the statistical software Minitab ver. 16.0 (Minitab lnc, 1994) to find out the similarities or significant differences. Statistical differences among the means were assessed using the LSD test at α = 0.05. Data were tested for normality before analysis. Differences in each parameter value on the host plants were tested for significance by estimating variances through the jackknife procedure (Meyer *et al.,* 1986; Maia *et al.,* 2000). The steps for the application of the method were as follows:

a) Estimation of each reproduction parameter using the survival and fecundity data from all of the *n* females is referred to as the true calculation. At this point, called step zero, the estimates obtained are denoted as $GFR_{(all)}$, $GFrR_{(all)}$, $NFR_{(all)}$, $NFrR_{(all)}$, and so on.

b) The procedure described in part (a) is repeated for n times, each time excluding a different female. In so doing, in each step *i*, data of *n-1* females are taken to estimate the parameters for each step, now named $GFR_{(i)}$, $GFrR_{(i)}$, $NFR_{(i)}$, $NFrR_{(i)}$, etc.

c) In each step *i*, pseudo-values are calculated for each parameter, subtracting the estimate in step zero from the estimate in step *i*. For instance, the pseudo-values of $GFR_{(j)}$ were calculated for the *n* samples using the following equation:

$GFR_{(j)} = n \times GFR_{(all)} - (n\text{-}1) \times GFR_{(i)}$

d) After calculating all of the *n* pseudo-values for *GFR*, jackknife estimates of the mean, $GFR_{(mean)}$, variance, $VARGFR_{(mean)}$, and standard error, $SEGFR_{(mean)}$, were calculated by the following equations:

$$GFR_{(mean)} = \frac{\sum_{j=1}^{n} GFR_{(j)}}{n}$$

$$VARGFR_{(mean)} = \frac{\sum_{j=1}^{n} (GFR_{(j)} - GFR_{(all)})^2}{(n-1)}$$

$$SEGFR_{(mean)} = \sqrt{\frac{VARGFR_{(mean)}}{n}}$$

For mean values of (n-1), jackknife pseudo-values for each variety were subjected to an analysis of variance (Maia *et al.,* 2000).

Model-based survival profile

Life-table data of *H. armigera* were explored for patterns in survival. The Weibull (following equation) model was used to determine the shape of survivorship curve with adult age *t* (in days).

$S_t = e^{-(t/b)c}, (t > 0)$

This survival model (Carey, 2001) uses the Weibull distribution (Gurney and Nisbet, 1998). Here *b* is the scale and *c* the shape parameters (Carey, 2001). Values of *c* parameter correspond to survival curve type I (c > 1), II (c = 1), or III (c < 1), respectively.

Model evaluation was made based upon goodness-of-fit. Statistical values of R^2 and residual sum of squares (RSS) of the model on various host plants were used to discriminate model fitness among host plants.

A dendrogram of various host plants based on reproduction parameters of *H. armigera* reared on various host plants was created after cluster analysis by Ward's method using the statistical software SPSS 18.0 (SPSS, 2007).

Results

Reproduction parameters

The reproduction parameters of *H. armigera* adults developed from larvae reared on various host plants are summarized in Table 1. The gross hatch rate of *H. armigera* was 98.5, 99.5, 99.0, 99.5, 93.0, 94.5, 99.0, 89.0 and 79.5 % on chickpea Hashem, cowpea Mashhad, chickpea Bivanij, chickpea Arman, white kidney bean Dehghan, red kidney bean Goli, chickpea Azad, common bean Khomein and tomato Meshkin, respectively. The highest rate of gross fecundity ($F = 5181.7$; df = 8, 168; $P < 0.01$) was on chickpea Arman (2947.8 ± 7.8 eggs female[-1]), whereas the lowest value of this parameter was on tomato Meshkin (847.5 ± 9.2 eggs female[-1]). Among various host plants, the gross fertility rate ($F = 6861.82$; df = 8, 168; $P < 0.01$) was the highest on chickpea Arman (2933.0 ± 7.8 eggs female[-1]) and lowest on tomato Meshkin (673.8 ± 7.3 eggs female[-1]). The net fecundity rate

($F = 14189.09$; df = 8, 172; $P < 0.01$) varied from 2404.2 ± 7.1 to 225.5 ± 2.6 eggs, which was highest on chickpea Arman and lowest on tomato Meshkin. Also, the net fertility rate ($F = 15945.31$; df = 8, 172; $P < 0.01$) was highest on chickpea Arman (2392.2 ± 7.1 eggs female[-1]) and lowest on tomato Meshkin (179.3 ± 2.1 eggs female[-1]). The mean daily number of eggs laid per female ($F = 2988.1$; df = 8, 168; $P < 0.01$) ranged from 67.9 ± 0.7 to 170.9 ± 0.4 eggs, which was the minimum on tomato Meshkin and the maximum on chickpea Arman. However, the maximum number of fertile eggs laid per female ($F = 4423.78$; df = 8, 168; $P < 0.01$) was on chickpea Arman (170.1 ± 0.4 eggs) and the minimum was on tomato Meshkin (54.0 ± 0.5 eggs).

Mortality and growth indices

The percentage of mortality and the growth index of *H. armigera* on various host plants are given in Table 2. The highest percentage of larval mortality (50%) was observed on tomato Meshkin and the highest percentage of pupal mortality (15.78%) was on common bean Khomein. No pre-pupal mortality was observed on various host plants. The lowest percentage (8%) of larval mortality was obtained on chickpea Arman. However, the mortality of overall immature stages was highest on tomato Meshkin (58%) and lowest on chickpea Arman (8%).

Among the various host plants, the highest growth indices of larval, pre-pupal, pupal and overall immature stages of *H. armigera* (2.86, 24.22, 5.47 and 1.57, respectively) were on chickpea Arman. The lowest growth indices of pre-pupal, pupal and overall immature stages were 17.54, 3.31 and 1.10 on tomato Meshkin, respectively. However, the growth index of larval stage was lower on red kidney bean Goli compared with the other host plants.

The results showed that various host plants as larval food had a significant effect (F = 231.49; df = 8, 107; $P < 0.01$) on fitness index of *H. armigera*, which was highest on cowpea Mashhad and chickpea Arman (0.347 ± 0.009 and 0.349 ± 0.009 gr day[-1], respectively) and lowest on tomato Meshkin (0.052 ± 0.001 gr day[-1]) (Fig. 1). Also, the standardized insect-growth index of *H.*

armigera showed significant difference (F = 148.87; df = 8, 107; P < 0.01) among host plants, being highest on cowpea Mashhad and chickpea Arman (0.057 ± 0.001 and 0.058 ± 0.001 gr day^{-1}, respectively) and lowest on tomato Meshkin (0.013 ± 0.000 gr day^{-1}) (Fig. 2).

Table 1 Reproduction parameters (Mean ± SE) of *Helicoverpa armigera* on nine host plants under laboratory conditions.

	Parameters (mean ± SE)						
Host (variety)	**Gross fecundity rate**	**Gross fertility rate**	**Net fecundity rate**	**Net fertility rate**	**Gross hatch rate (%)**	**Daily eggs per female**	**Daily fertile eggs per female**
Chickpea (Hashem)	2355.9 ± 3.4d	2320.6 ± 3.3d	1838.7 ± 2.8d	1811.1 ± 2.8d	98.5	133.0 ± 0.2d	131.1 ± 0.1d
Cowpea (Mashhad)	2076.0 ± 9.9e	2065.6 ± 9.8e	1497.6 ± 5.2e	1490.1 ± 5.2e	99.5	125.5 ± 0.5e	124.8 ± 0.5e
Chickpea (Bivanij)	2572.3 ± 6.4b	2546.5 ± 6.3b	2086.4 ± 5.7b	2065.5 ± 5.6b	99.0	144.5 ± 0.3b	143.1 ± 0.3b
Chickpea (Arman)	2947.8 ± 7.8a	2933. 0 ± 7.8a	2404.2 ± 7.1a	2392.2 ± 7.1a	99.5	170.9 ± 0.4a	170.1 ± 0.4a
White kidney bean (Dehghan)	1654.1 ± 15.6g	1538.3 ± 14.5g	885.6 ± 10.7g	823.6 ± 9.9g	93.0	106.2 ± 1.0f	98.8 ± 0.9f
Red kidney bean (Goli)	1829.3 ± 7.3f	1728.7 ± 6.9f	1165.5 ± 5.9f	1101.4 ± 5.6f	94.5	97.7 ± 0.3g	92.4 ± 0.3h
Chickpea (Azad)	2442.7 ± 4.1c	2418.3 ± 4.1c	1967.6 ± 3.0c	1947.9 ± 3.0c	99.0	135.7 ± 0.2c	134.3 ± 0.2c
Common bean (Khomein)	1571.1 ± 10.3h	1398.3 ± 9.1h	780.4 ± 3.5h	694.5 ± 3.1h	89.0	107.6 ± 0.7f	95.7 ± 0.6g
Tomato (Meshkin)	847.5 ± 9.2i	673.8 ± 7.3i	225.5 ± 2.6i	179.3 ± 2.1i	79.5	67.9 ± 0.7h	54.0 ± 0.5i

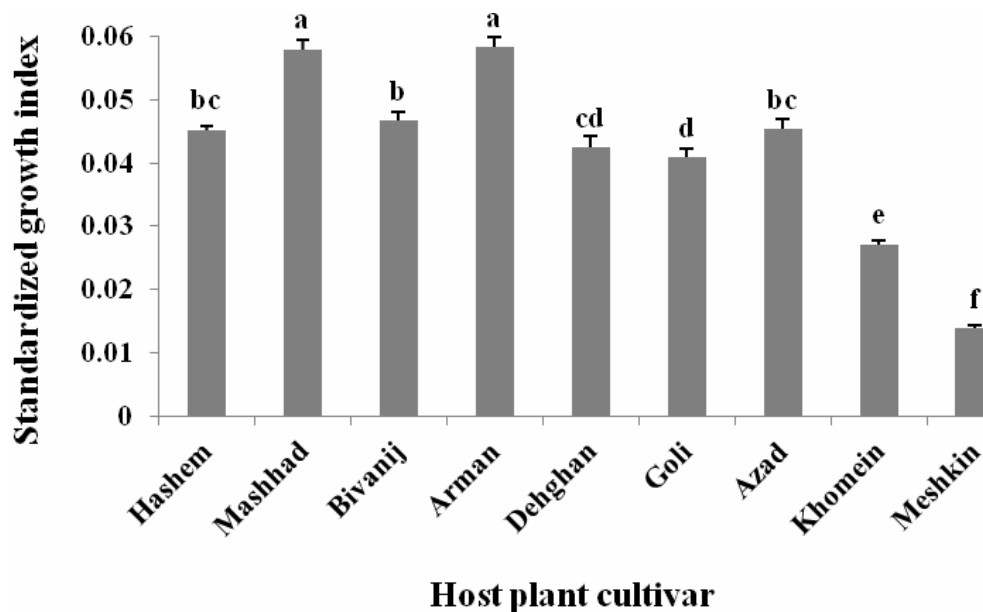The means followed by different letters in the same columns are significantly different (LSD, *P* < 0.01).

Table 2 Percentage of mortality and growth index (G. I.) of *Helicoverpa armigera* on nine host plants under laboratory conditions.

	Larva		Pre-pupa		Pupa		Overall immature	
Host (variety)	Mortality (%)	G. I.	Mortality (%)	G. I.	Mortality (%)	G.I.	Mortality (%)	G. I.
Chickpea (Hashem)	14.00 (50)	2.80	0.00 (43)	23.03	0.00 (43)	5.28	14.00 (50)	1.54
Cowpea (Mashhad)	10.00 (50)	2.79	0.00 (45)	23.26	0.00 (45)	5.31	10.00 (50)	1.53
Chickpea (Bivanij)	10.00 (50)	2.85	0.00 (45)	23.73	0.00 (45)	5.38	10.00 (50)	1.56
Chickpea (Arman)	8.00 (50)	2.86	0.00 (46)	24.22	0.00 (46)	5.47	8.00 (50)	1.57
White kidney bean (Dehghan)	18.00 (50)	2.53	0.00 (41)	21.63	12.19 (41)	3.35	28.00 (50)	1.20
Red kidney bean (Goli)	16.00 (50)	1.26	0.00 (42)	19.09	7.14 (42)	3.42	22.00 (50)	1.26
Chickpea (Azad)	14.00 (50)	2.81	0.00 (43)	23.50	0.00 (43)	5.34	14.00 (50)	1.54
Common bean (Khomein)	24.00 (50)	2.08	0.00 (38)	19.04	15.78 (38)	3.34	36.00 (50)	1.13
Tomato (Meshkin)	50.00 (80)	2.00	0.00 (40)	17.54	10.00 (40)	3.31	58.00 (80)	1.10

Numerals in parentheses are the number of samples tested.
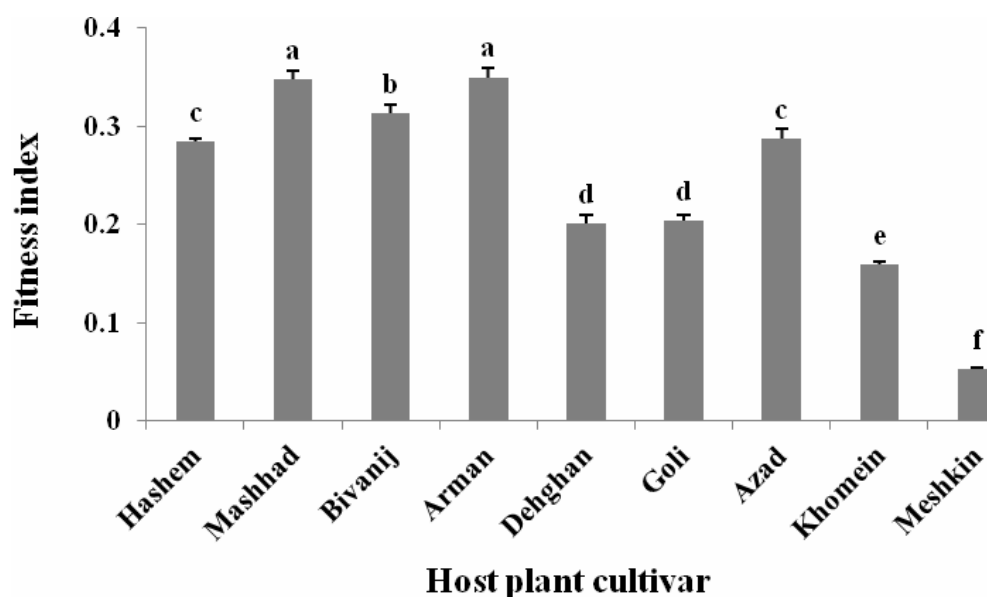
Figure 1 The fitness index of *Helicoverpa armigera* on nine host plants under laboratory conditions. Bars represent standard error of the means. The means followed by different letters are significantly different (LSD, *P* < 0.01).

Figure 2 The standardized insect-growth of *Helicoverpa armigera* on nine host plants under laboratory conditions. Bars represent standard error of the means. The means followed by different letters are significantly different (LSD, *P* < 0.01).

Table 3 Estimated parameters of non-linear regression between adult survivorship and age of *Helicoverpa armigera* reared on various host plants (fitted to Weibull model).

| Hosts | Parameters | | | | 95% Confidence Interval | | | |
| | | | | | for parameter b | | for parameter c | |
	$b \pm SE$	$c \pm SE$	R^2	RSS	Lower	Upper	Lower	Upper
Chickpea (Hashem)	19.802 ± 0.132	4.553 ± 0.182	0.993	0.022	19.530	20.074	4.177	4.982
Cowpea (Mashhad)	19.219 ± 0.208	3.361 ± 0.166	0.988	0.045	18.791	19.646	3.019	3.703
Chickpea (Bivanij)	19.502 ± 0.293	4.480 ± 0.396	0.969	0.114	18.900	20.106	3.664	5.294
Chickpea (Arman)	18.950 ± 0.216	4.344 ± 0.282	0.985	0.067	18.506	19.392	3.765	4.922
White kidney bean (Dehghan)	17.317 ± 0.160	4.690 ± 0.266	0.990	0.035	16.985	17.650	4.138	4.922
Red kidney bean (Goli)	20.543 ± 0.136	7.174 ± 0.434	0.987	0.032	20.261	20.825	6.273	8.075
Chickpea (Azad)	19.654 ± 0.140	6.226 ± 0.353	0.990	0.033	19.363	19.944	5.496	6.957
Common bean (Khomein)	15.955 ± 0.100	6.810 ± 0.367	0.993	0.017	15.746	16.164	6.040	7.580
Tomato (Meshkin)	14.563 ± 0.191	3.304 ± 0.197	0.986	0.033	14.163	14.946	2.889	3.719

Model-based survival profile

Parameters of non-linear regression analysis between adult survivorship and age of *H. armigera* reared on various host plants, using Weibull model, are summarized in Table 3. A significant fit was obtained with the Weibull model for adult *H. armigera* survival on all experimental host plants. The scale parameter (*b*) was higher on red kidney bean Goli than on other host plants, revealing a significant survival differential. The parameter values ranged between 14.563 for tomato Meshkin (R^2 = 0.986, RSS = 0.033) and 20.543 for red kidney bean Goli (R^2 = 0.987, RSS = 0.032). Among various host plants, the parameters obtained for common bean Khomein caused better fit of Weibull model to our experimental data (R^2 = 0.993, RSS = 0.017) in comparison with the other host plants. For all host plants, the shape parameter (*c*) of the Weibull model corresponded to type I survival curve (*c* > 1; Fig. 3). However, after 95% confidence interval for the parameter *c* on various host plants, a significant difference was detected in quantities of this parameter among some of tested plant varieties via binary comparisons (Table 3); but, as mentioned already, the pattern of survivorship was distinguished as type I on all tested host plants.

Cluster analysis

A dendrogram according to reproductive performance of *H. armigera* reared on various host plants is shown in Fig. 4. The dendrogram shows two clusters labeled A (including subclusters A1 and A2) and B (including subclusters B1 and B2). Different host plants were grouped within each cluster according to the reproductive performance of *H. armigera* reared on the nine host plant varieties. Cluster A included subclusters A1 (chickpeas Hashem, Azad and Bivanij) as an intermediate group; and A2 (chickpea Arman) as a suitable host; cluster B consisted of subclusters B1 (white kidney bean Dehghan, common bean Khomein, cowpea Mashhad and red kidney bean Goli) and B2 (tomato Meshkin) as unsuitable hosts.
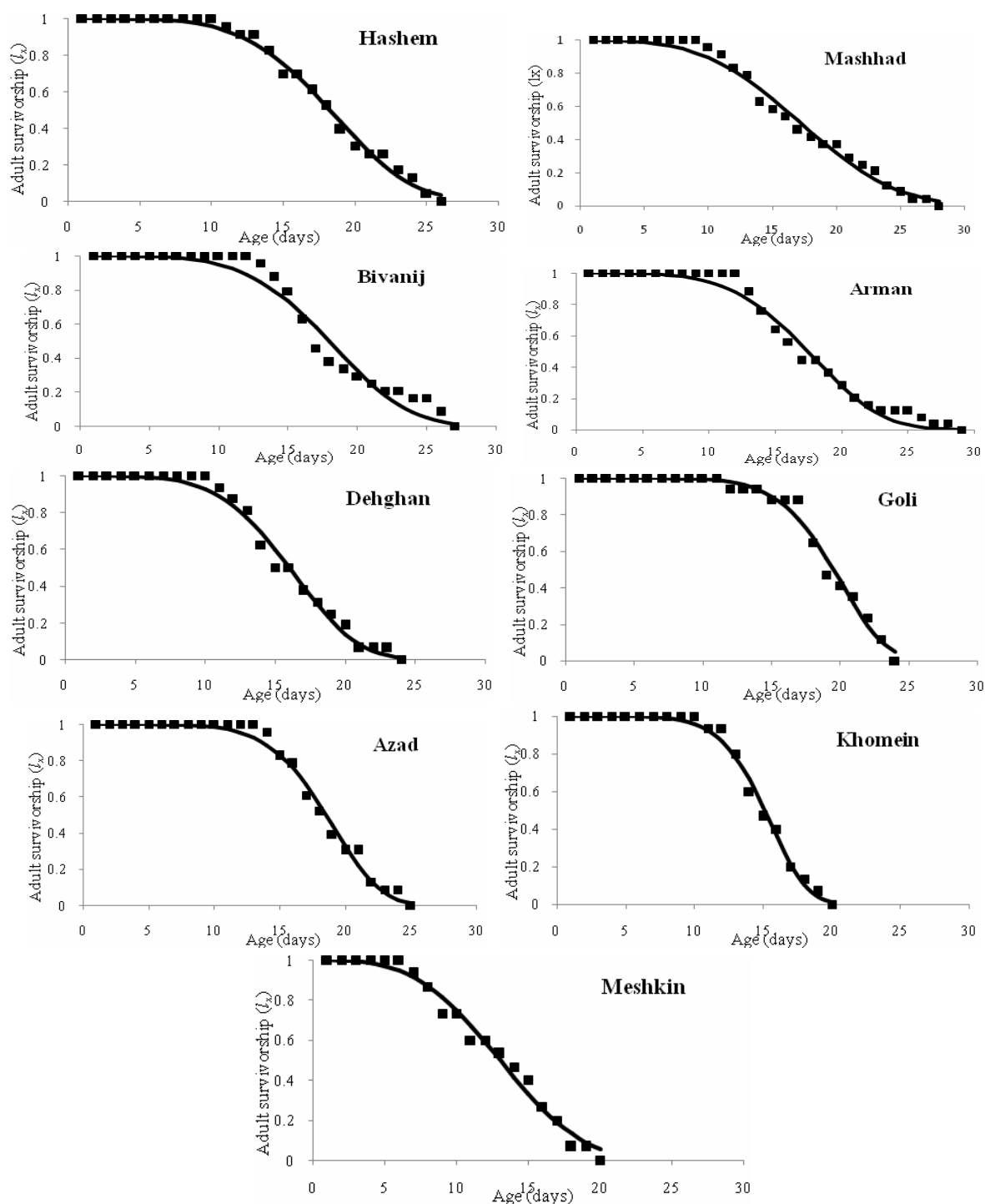
Figure 3 Fitting Weibull survival model to observed values of age-specific survivorship (*lx*) of *Helicoverpa armigera* on various host plants.
Dotted lines and solid lines represent observed data and model estimated, respectively.

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Rescaled Distance Cluster Combined
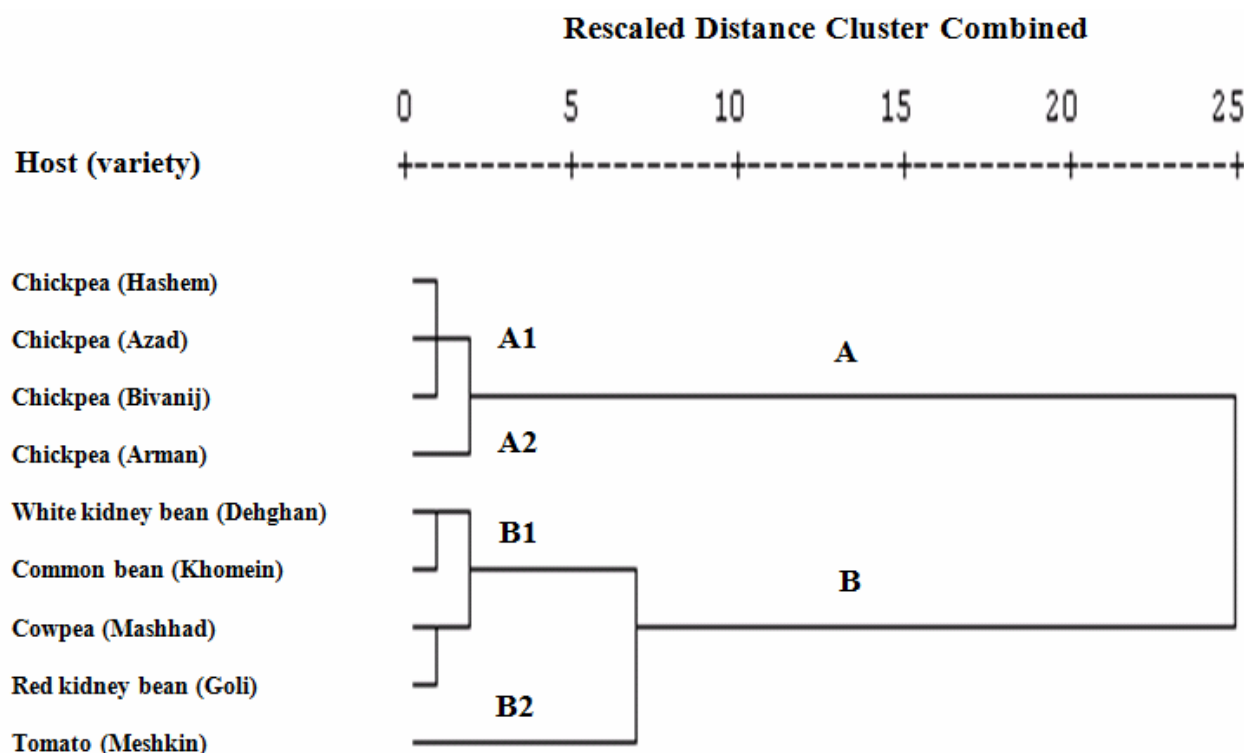
Figure 4 Dendrogram of various host plants according to reproductive parameters and growth indices of *Helicoverpa armigera* reared on nine host plants under laboratory conditions (Ward's method).

Discussion

Various host plants can affect life history traits of the insects such as development, survival and reproductive rates (Tsai and Wang, 2001; Kim and Lee, 2002), and have a main role in regulating insect populations (Umbanhowar and Hastings, 2002). The shorter developmental time and greater total reproduction of insects on a host plant indicate greater suitability of that plant (van Lenteren and Noldus, 1990). Applying resistant varieties plays a key role in integrated pest management programs (Wilson and Huffaker, 1976; Endo *et al.,* 2007). The partially resistant varieties also may increase the effectiveness of biological and chemical control methods as part of an IPM strategy. Consequently, knowledge of varietal susceptibility or resistance and reproductive capacity of a pest might be fundamental components of an integrated pest management

program for any crop. Such information can aid in detecting and monitoring pest infestations, variety selection, and crop breeding (Razmjou *et al.,* 2006).

The reproduction parameters of *H. armigera* were affected by various host plants. Females reared as larvae on chickpea Arman had a higher rate of fecundity and fertility than those reared on the other host plants, suggesting that it can be more suitable to this pest as compared with the other host plants examined. The results from the study of life table parameters of *H. armigera* on various host plants indicated that the larval period and development time of this pest were shorter on chickpea Arman than the other host plants and this variety was a more suitable host plant for development of the immature stages (Hemati *et al.,* 2012c). The data obtained in that research on chickpea Arman as susceptible host is in agreement with the findings of the current study on the

reproduction performance and growth indices of *H. armigera*. Differences in the reproduction performance and growth indices of the pest on various host plants could be the result of variation in nutrients required by the pest or variation in the levels of secondary metabolites. The unsuitability of some host plants of *H. armigera* may be due to the presence of some phytochemicals in these host plants acting as antixenotic and/or antibiotic agents or the absence of primary nutrients essential for the growth and development of *H. armigera* (Naseri *et al.,* 2009a). The gross fecundity rate of *H. armigera* ranged from 847 eggs on tomato Meshkin to 2947 eggs on chickpea Arman, which was higher than that reported by Naseri *et al.,* (2011) on different soybean varieties (ranging from 467 to 2736 eggs on Gorgan 3 and M4, respectively). According to the results of Mironidis and Savopoulou-Soultani's (2008) studies, the gross fecundity rate of *H. armigera* was 1008 eggs on an artificial diet based on maize meal at 25ºC. Fecundity per female of *H. armigera* varied from 285 eggs on maize to 743 eggs on an artificial diet (Jallow *et al.,* 2001). Some possible causes for such disagreement may be because of physiological differences depending on the kind of host, genetic variations as a result of laboratory rearing or difference in geographic populations of the pest. Our finding on the number of daily eggs laid per female on tomato Meshkin (67 eggs) is almost the same as the observation reported on soybean JK (64 eggs) (Naseri *et al.,* 2011).

The results showed that the lowest larval mortality was on chickpea Arman (8%), and the highest on tomato Meshkin (50%). Arghand (2011) reported that the larval mortality, among various maize hybrids, varied from 58 to 62%. According to Fathipour and Naseri (2011), the highest larval mortality of *H. armigera* on soybean varieties was on L17 (29.63%). The result for the highest pupal mortality of *H. armigera* fed on common bean Khomein (15.78%) was almost the same as that reported on soybean M7 (13.64%) (Naseri *et al.,* 2009a). In this study, the highest and lowest values of larval growth

index of *H. armigera* were respectively on chickpea Arman (2.86) and red kidney bean Goli (1.26). Also, Fathipour and Naseri (2011) and Arghand (2011) reported that the lowest larval growth index was 2.68 on soybean L17, and 1.54 on corn hybrid DC370.

Our observations on survivorship curves of adult *H. armigera* on various host plants using Weibull frequency distribution are in agreement with those reported by Karimi *et al.,* (2012), who showed that there was a significant fit between the survivorship of adult *H. armigera* and this model on different canola cultivars. Also, the reported values of parameter c ($c > 1$) for this pest on canola cultivars by Karimi *et al.,* (2012) are similar to our findings in the present study.

The results of the cluster analysis represented here indicated that grouping within each cluster might be due to a high level of physiological similarity of various host plants. The results of the comparative reproductive parameters of *H. armigera* on various host plants revealed that subcluster B2 was the least suitable and subcluster A2 was the most suitable host plant for *H. armigera*. However, the hosts in subclusters A1 and B1 had an intermediate status. These results were associated with reproductive parameters and growth index values on various host plants. According to Table 1 for reproductive parameters of *H. armigera*, the gross fecundity, gross fertility, net fecundity and net fertility rates were the highest on chickpea Arman and lowest on tomato Meshkin compared with the others. The results of life table parameters of *H. armigera* reared on various host plants indicated that the longest development time, the lowest net reproductive rate (R_0) and intrinsic rate of increase (r_m) values were on tomato Meshkin and the shortest development time, highest net reproductive rate and highest intrinsic rate of increase were on chickpea Arman (Hemati *et al.,* 2012d), which are in agreement with the current research. Also, working on the nutritional indices and digestive proteolytic and amylolytic activities of *H. armigera* reared on different host plants,

Hemati *et al.,* (2012a, b) showed that the ECI (efficiency of conversion of ingested food) and ECD (efficiency of conversion of digested food) values and digestive proteolytic and amylolytic activities were lowest on tomato Meshkin, which are in agreement with the present study regarding reproductive parameters on this host. Our results related to unsuitability of tomato Meshkin is in agreement with the findings of Liu *et al.,* (2004), who studied life table parameters of *H. armigera* on different host crops and reported that tomato and hot pepper are classified as unsuitable hosts for *H. armigera*. By combining the results from earlier studies on the nutritional indices (Hemati *et al.,* 2012a), proteolytic and amylolytic activities (Hemati *et al.,* 2012b), life history (Hemati *et al.,* 2012c) and population growth parameters (Hemati *et al.,* 2012d) of *H. armigera* on tomato Meshkin, and the findings of the present research on the reproductive performance and growth indices on this variety, it could be deduced that maybe the presence of some PIs (protease inhibitors) in this variety, as an antibiosis factor, was responsible for the weak performance of *H. armigera* fed on this variety.

There are many factors affecting host suitability (such as nutrient content and secondary compounds of the host), and the ability of digestion and assimilation by the insect (Liu *et al.,* 2004). Knowledge of the differences in host plants and food quality among various host plants could have beneficial implications for management of insect pests (Greenberg *et al.,* 2001; Saeed *et al.,* 2009). For a better understanding of the insect-plant interaction to control *H. armigera*, more attention should be focused on demographic and reproductive parameters of this pest when reared on various host plants under semi-field and field conditions. Also, further study will be needed to determine the biochemical basis of multiple-insect resistance in the host plants examined especially in tomato. Understanding the host plant resistance mechanisms will help in the improvement of tomato varieties with enhanced pest resistance and may result in decreased insecticide usage.

Acknowledgments

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پارامترهای تولید مثل و شاخص‌های رشد کرم غوزه‌ی پنبه، *Helicoverpa armigera* (Lepidoptera: Noctuidae) روی میزبان‌های مختلف گیاهی

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چکیده: تأثیر میزبان‌های مختلف گیاهی شامل نخود (ارقام آرمان، هاشم، آزاد و بیونیج)، لوبیا چیتی (رقم خمین)، لوبیا سفید (رقم دهقان)، لوبیا قرمز (رقم گلی)، لوبیا چشم‌بلبلی (رقم مشهد) و گوجه‌فرنگی (رقم مشکین) روی پارامترهای تولید مثل و شاخص‌های رشد کرم غوزه‌ی پنبه، *Helicoverpa armigera* (Hübner)، تحت شرایط آزمایشگاهی (دمای ۱ ± ۲۵ درجه‌ی) سلسیوس، رطوبت نسبی ۵ ± ۶۵ درصد و دوره‌ی نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی تعیین شد. بیش‌ترین نرخ‌های ناخالص باروری، ناخالص بارآوری، خالص باروری، خالص بارآوری، تخم‌های گذاشته شده در هر روز توسط هر فرد ماده و تخم‌های گذاشته شده‌ی بارآور در هر روز توسط هر فرد ماده روی نخود رقم آرمان بود (به‌ترتیب ۷/۸ ± ۲۹۴۷/۸، ۷/۸ ± ۲۹۳۳/۰، ۷/۱ ± ۲۴۰۴/۲، ۷/۱ ± ۲۳۹۲/۲، ۰/۴ ± ۱۷۰/۹ و ۰/۴ ± ۱۷۰/۱ تخم)، درحالی‌که کم‌ترین مقدار این پارامترها روی گوجه‌فرنگی رقم مشکین بود (به‌ترتیب ۹/۲ ± ۸۴۷/۵، ۷/۳ ± ۶۷۳/۸، ۲/۶ ± ۲۲۵/۵، ۲/۱ ± ۱۷۹/۳، ۰/۷ ± ۶۷/۹ و ۰/۵ ± ۵۴/۳ تخم). شاخص رشد مجموع مراحل نابالغی از ۱/۱۰ تا ۱/۵۷ متغیر بود که کم‌ترین آن روی گوجه‌فرنگی رقم مشکین و بیش‌ترین آن روی نخود رقم آرمان بود. همچنین، شاخص‌های قابلیت زیستی و رشد استاندارد روی نخود رقم آرمان بیش‌ترین (به‌ترتیب ۰/۰۰۹ ± ۰/۳۴۹ و ۰/۰۰۱ ± ۰/۰۵۸ گرم بر روز) و روی گوجه‌فرنگی رقم مشکین کم‌ترین (به‌ترتیب ۰/۰۰۱ ± ۰/۰۵۲ و ۰/۰۰۰ ± ۰/۰۱۳ گرم بر روز) بودند. به‌منظور توصیف منحنی بقاء افراد بالغ *H. armigera* روی میزبان‌های مختلف گیاهی مورد آزمایش از مدل Weibull استفاده شد. برازش معنی‌داری با مدل Weibull برای افراد بالغ *H. armigera* در همه‌ی میزبان‌های گیاهی مورد آزمایش به‌دست آمد. نتایج حاصل از پارامترهای تولید مثل، شاخص‌های رشد و تجزیه‌ی کلاستر نشان دادند که گوجه‌فرنگی رقم مشکین، میزبانی نسبتاً مقاوم به *H. armigera* بود.

واژگان کلیدی: کرم غوزه‌ی پنبه، پارامترهای تولید مثل، شاخص‌های رشد، میزبان گیاهی