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Research Article

Development, reproduction and life table parameters of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on five main host plants

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Abstract: The cotton bollworm, *Helicoverpa armigera* (Hübner), is a destructive pest on a wide range of economic crops in many parts of the world. In this research, demographic parameters of *H. armigera* were determined on five host plant species including cowpea (cv. Mashhad), navy bean (cv. Dehghan), chickpea (cv. Hashem), soybean (cv. 033) and corn (cv. Single cross 704). All experiments were carried out under laboratory conditions at 25 ± 1°C, 65 ± 5% RH and a photoperiod of 16: 8 (L: D) h. The results revealed that females and males had the shortest development time on chickpea (36.16 and 34.98 d, respectively) and the longest development time on corn (42.00 and 42.95 d, respectively). The highest daily and total fecundity of *H. armigera* were observed on cowpea and the lowest ones were on corn. The values of the intrinsic rate of increase (r_m) on the above-mentioned host plants were 0.180, 0.144, 0.161, 0.161 and 0.126 day^{-1}, respectively. Also, the values of the net reproductive rate (R_0) were 365.66, 294.28, 365.67, 239.69 and 147.40 female offspring, respectively. The longest mean generation time (T) (37.90 ± 0.26 d) and doubling time (DT) (5.62 ± 0.17 d) were observed on corn. Our findings revealed that cowpea and corn were the most susceptible and resistant host plants to *H. armigera*, respectively.

Keywords: cotton bollworm, *Helicoverpa armigera,* corn, cowpea

Introduction

The cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a cosmopolitan and destructive pest, feeding on a diverse array of host plant species (Fathipour *et al.,* 2019). It frequently attacks over 200 crop species including cotton, maize, chickpea, pigeon pea, sorghum, tomato and soybean (Sedaratian *et al.,* 2014). The neonate larvae feed on different parts of host plants such as flower, bud, stem and leaves (Garcia, 2006). It has been shown that chemical control cannot be a permanent tool for the control of this pest either due to the environmental problems which restrict the long-term application of pesticides or growing resistance to the different classes of chemicals (Sedaratian *et al.,* 2013). Use of genetically resistant host plants is an important approach which helps to diminish

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the damage of *H. armigera*. Also, it can be integrated successfully with other non-chemical managing approaches (Fathipour and Sedaratian, 2013; Fathipour *et al.,* 2019).

Different host plants can affect the feeding behavior of insect pests positively or negatively (Jafari *et al.,* 2020) through targeting their development time, survival rate, reproduction and life table parameters (Golizadeh *et al.*, 2009; Soufbaf *et al.*, 2010a, b; Soufbaf *et al.*, 2012). Demographic parameters provide a simple way to extract detailed information about the population growth potential of an insect pest in the current and the next generations (Frei *et al.,* 2003). Also, understanding the demographic parameters of a pest helps us to assess the level of resistance to insect pests in different host plants. Such information can be utilized appropriately in integrated pest management (IPM) programs.

Although, valuable information exists on the demographic parameters of *H. armigera* on each of these host plants separately (Ali *et al.*, 2009; Naseri *et al.,* 2009a,b; Soleimannejad *et al.,* 2010; Naseri *et al.*, 2011; Karimi *et al.*, 2012), no information is available regarding comparative demography of *H. armigera* on these host plants. In this study, we aimed to study the demographic parameters of *H. armigera* on the above-mentioned host plants using artificial diet prepared from their seeds. The artificial diet provides suitable conditions for successive rearing of *H. armigera* to assess its potential on these host plants. Such information would be useful in the integrated pest management of *H. armigera* especially in areas where these plant species are planted at the same time.

Materials and Methods

Plant seeds

The seeds of five different host plants including cowpea (cv. Mashhad), chickpea (cv. Hashem), soybean (cv. 033), navy bean (cv. Dehghan) and corn (cv. Sc704) were obtained from Seed and Plant Improvement Institute, Karaj, Iran.

Rearing methods and experimental conditions

The eggs of *H. armigera* were prepared from a laboratory culture kept on an artificial diet at the Tabriz University, Iran. Five separate stock cultures of *H. armigera* were reared for two generations on artificial diets based on the seeds of five host plants. The rearing was performed in a growth chamber set at 25 ± 1 °C, 65 ± 5% RH, and a photoperiod of 16: 8 (L: D) h.

The artificial diets were prepared as follows: powdered seed of each host plant (250 g), wheat germ (30 g) as protein and carbohydrate sources, sorbic acid (1.1 g) as an antimicrobial agent, ascorbic acid (3.5 g) as a vitamin source, sunflower oil (5 ml) as a preservative, agar (14 g) as a moisturizer, methyl-p-hydroxyl benzoate (2.2 g), formaldehyde 37% (2.5 g) and distilled water (650 ml) (Teakle, 1991).

To obtain the same-aged eggs, 15-20 pairs of adult moths (both sexes) of *H. armigera* emerged from the pupae were transferred to the mating cages (14 cm diameter and 19 cm height) for 72 h. The mating cages were covered at the top with a fine mesh net. A small cotton roll soaked in 10% honey solution was applied for supplying the adults. The eggs laid on the net were harvested for running the experiment.

Determining demographic parameters

Seventy eggs were used to determine survivorship and development of *H. armigera* on each host plant. All eggs were checked daily and the number of emerged larvae was recorded. The newly hatched larvae were transferred individually into plastic containers using fine camel hair brush. The plastic containers were 8 cm in diameter and 5 cm in height with a hole covered by a fine mesh net for ventilation. Fresh artificial diet was provided as required and observations were made daily to record the mortality/survival of larvae in the same instar or molting to the next instar up to adult emergence. The larval instars were recognized by measuring the head capsules or presence of exuviae from molting. The fifth instar larvae were kept in the plastic containers for prepupation and pupation. The pupae were also checked daily until all adults emerged or the pupae died. At pupation, the gender was determined and recorded.

After adults' emergence, a pair of female and male moths was transferred into the oviposition cages (as described above). A small cotton wick soaked in 10% honey solution was placed in the oviposition cages to nourish the adults. The adults were introduced into new oviposition cages daily and the laid eggs were counted and harvested once a day. The adult longevity, oviposition period and fecundity were determined until the death of the last female in the cohort.

The life table parameters of *H. armigera* on their hosts were determined using the formulae explained by Carey (1993) and the net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), mean generation time (T) and doubling time (DT) were estimated. In addition, age-specific survivorship (l_x) and life expectancy (e_x) were calculated.

Data analysis

To estimate the variance for r_m and other life table parameters, the jackknife method was used (Meyer *et al.,* 1986). The technique is based on the repeated recalculation of the required estimator and missing out each sample in turn (Maia *et al.,* 2000). The jackknife pseudo-values for hosts were tested for normality and then subjected to an analysis of variance (ANOVA) (PROC GLM, SAS Institute). Based on the results, mean comparison was done based on Tukey test ($P < 0.05$) (SAS version 9.4).

Cluster analysis

A dendrogram was constructed for the studied hosts based on the demographic parameters estimated for *H. armigera* on these host plants using the statistical software SPSS (SPSS version 16.0).

Results

Development of immature stages

Except incubation time, the other immature stages had significant differences on different hosts studied. The larvae fed on the corn diet had a longer larval period (23.52 ± 0.43 days) than those fed on the other host plants (Table 1). Also, significant differences in the length of development time and total life span of female individuals of *H. armigera* were found on these hosts. The shortest (35.21 ± 0.35 days) and longest (42.72 ± 0.28 days) development time (egg to adult emergence) of *H. armigera* was observed on chickpea and corn, respectively.

Table 1 Duration (mean ± SE) of different life stages of *Helicoverpa armigera* on five different host plants.

Host plant	Incubation period (day)	Larval period (day)	Pre-pupal period (day)	Pupal period (day)	Development time (day)	Longevity (day)		Total lifespan (day)	
						Female	Male	Female	Male
Cowpea	3.09 ± 0.08a	17.20 ± 0.28c	3.02 ± 0.07b	13.90 ± 0.14b	37.07 ± 0.24c	12.56 ± 0.99b	11.61 ± 0.93a	49.33 ± 0.82b	48.56 ± 0.91a
Soybean	2.92 ± 0.05a	18.31 ± 0.30b	3.03 ± 0.06b	14.40 ± 0.13a	38.62 ± 0.24b	11.09 ± 0.67b	10.34 ± 0.82a	49.38 ± 0.76b	49.31 ± 0.76a
Corn	3.06 ± 0.08a	23.52 ± 0.43a	3.93 ± 0.11a	13.90 ± 0.31b	42.72 ± 0.28a	11.88 ± 0.59b	9.67 ± 1.15a	52.50 ± 1.10a	51.67 ± 0.68a
Navy bean	3.00 ± 0.06a	17.95 ± 0.39bc	2.94 ± 0.05b	13.68 ± 0.12b	37.90 ± 0.29bc	12.70 ± 0.48b	11.92 ± 0.90a	49.41 ± 0.62b	49.54 ± 0.95a
Chickpea	2.97 ± 0.06a	15.92 ± 0.22d	3.05 ± 0.12b	13.61 ± 0.14b	35.21 ± 0.35d	15.11 ± 0.46a	11.95 ± 0.68a	49.88 ± 0.52b	48.11 ± 1.06a
F	0.32	36.60	6.99	2.45	36.55	6.56	0.82	2.66	1.11
df	4, 150	4, 150	4, 149	4, 149	4, 149	4, 130	4, 108	4, 141	4, 110
P	0.868	< 0.001	< 0.001	0.049	< 0.001	< 0.001	0.516	0.035	0.356

The means in a column followed by the same letters are not significantly different (P < 0.05, Tukey's test).

Adult longevity and fecundity

The effect of five different diets on the adult longevity and reproduction of *H. armigera* are given in Table 1 and 2. The female adult longevity was significantly different on the diets examined (Table 1). The longest female adult longevity (15.11 ± 0.46 d) was found in the larvae feeding on chickpea. However, no significant difference in the longevity of male adults was found on the five diets tested.

Significant difference was found among five diets in terms of the total life span of female individuals (Table 1). The longest (52.50 ± 1.10 days) and shortest (49.33 ± 0.82 days) total life span of females were observed on corn and cowpea, respectively. However, no significant differences in the total life span were found among male individuals. The oviposition period and fecundity of *H. armigera* are summarized in Table 2. The females reared on cowpea had the highest daily fecundity (93.1 ± 9.32 eggs) (Table 2) and total fecundity (632.82 ± 50.75 eggs) (Table 2).

Table 2 **P**re- and post-oviposition and oviposition periods and fecundity of *Helicoverpa armigera* emerging from the larvae reared on five different host plants.

Host plant	Pre-oviposition period (day)	Oviposition period (day)	Post-oviposition period (day)	Fecundity (Egg/Female)	
				Daily	Total
Cowpea	2.86 ± 0.15c	6.33 ± 0.51b	5.38 ± 0.61a	93.11 ± 9.32a	632.82 ± 50.75a
Soybean	3.06 ± 0.23bc	6.33 ± 0.37b	3.93 ± 0.49bc	71.84 ± 6.34b	560.25 ± 47.75ab
Corn	3.80 ± 0.26a	5.47 ± 0.47b	3.38 ± 0.44c	55.74 ± 6.20b	352.00 ± 26.09c
Navy bean	3.42 ± 0.17ab	6.04 ± 0.30b	3.69 ± 0.35bc	69.00 ± 5.24b	466.24 ± 36.61bc
Chickpea	2.68 ± 0.10c	7.86 ± 0.40a	4.92 ± 0.35ab	75.67 ± 1.55ab	590.58 ± 39.73ab
F	5.96	5.02	3.41	3.92	5.64
df	4, 103	4, 104	4, 96	4, 98	4, 89
P	< 0.001	0.001	0.012	0.005	< 0.001

The means in a column followed by the same letters are not significantly different (P < 0.05, Tukey' test).

Survivorship and life expectancy

Age-specific survivorship (l_x) at the age of adult emergence of *H. armigera* on cowpea, soybean, corn, navy bean and chickpea was 0.86, 0.87, 0.59, 0.85 and 0.85, respectively (Fig. 1). Life expectancy (e_x) at the first day of the adult emergence on the above-mentioned diets was 10.88, 10.15, 9.55, 10.28 and 11.18 days, respectively (Fig. 2). At the beginning of life, the longest and shortest life expectancy was recorded on soybean (43.07days) and corn (37.82 days), respectively. Maximum age (the death of the last female) was observed on corn (58 days).

Reproductive parameters

The values of the reproductive parameters of *H. armigera* on five diets are presented in Table 3. The highest gross fecundity rate was observed on cowpea (778.02 eggs) and the lowest one was on corn (417.33 eggs) (Table 3). The gross fertility also showed significant differences among five different host plants tested. The highest value of the gross fertility was observed on chickpea (850.86 eggs). The lowest (135.78 eggs) and highest (933.59 eggs) net fecundity rates were observed on corn and chickpea (Table 3), respectively. The net fertility rate ranged from 681.52 to 50.24 eggs on chickpea and corn, respectively (Table 3).

Life table parameters

The life table parameters of *H. armigera* on the different diets are shown in Table 4. The net reproductive rate (R_0) was significantly different on different host plants tested (Table 4). The lowest R_0 was observed on corn (147.40 ± 6.69 female offspring/ female) and the highest one was on cowpea (365.66 ± 24.52 female offspring/ female). Furthermore, the intrinsic rate of increase (r_m) and finite rate of increase (λ) of *H. armigera* were significantly different on the five diets (Table 4). Among five different host plants, the highest value of r_m (0.180 ± 0.003 d^{-1}) and λ (1.192 ± 0.004 d^{-1}) were estimated on cowpea and the lowest value of these two parameters were observed on corn (0.126 ± 0.002 d^{-1} and 1.131 ± 0.004 d^{-1}, respectively). The results revealed significant differences among five diets in terms of the mean generation time (T) and doubling time (DT) (Table 4). The longest mean generation time (T) and doubling time (DT) were observed on corn (37.90 ± 0.26 d and 5.62 ± 0.17 d, respectively) and the shortest ones were obtained on cowpea (31.62 ± 0.22 d and 3.92 ± 0.08 d, respectively).

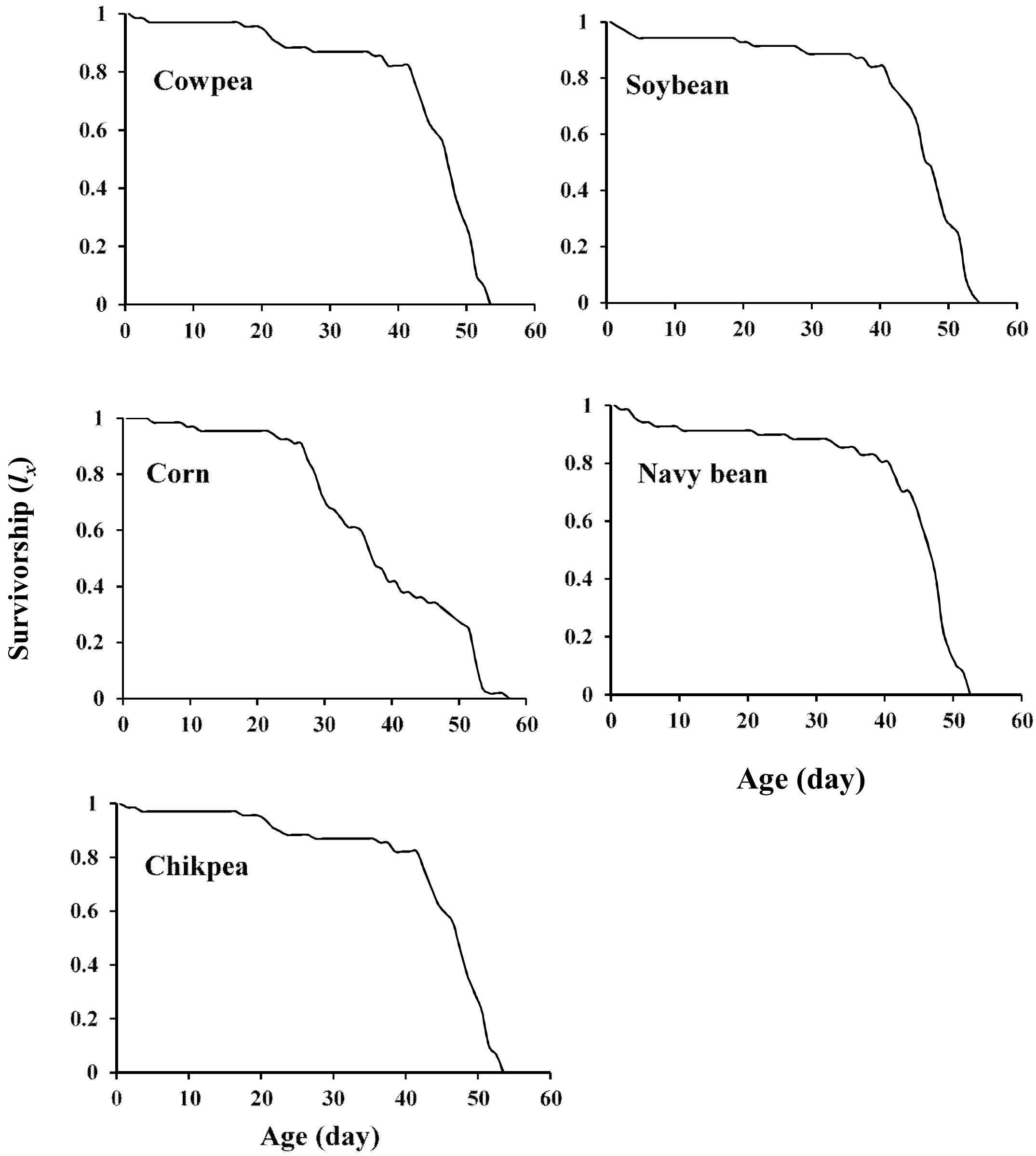

Figure 1 Survival rate (l_x) of *Helicoverpa. armigera* reared on five different host plants.

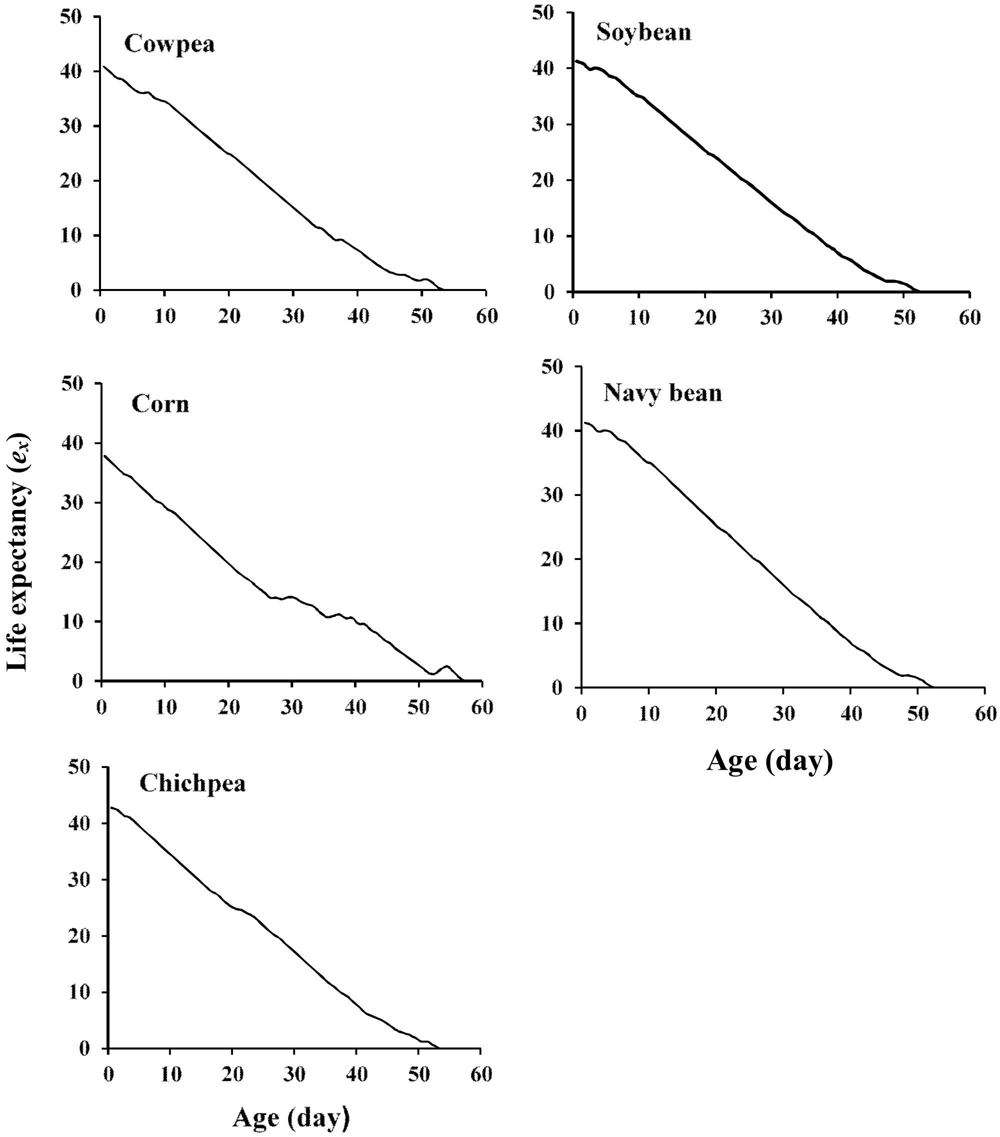

Figure 2 Life expectancy (e_x) of *Helicoverpa. armigera* reared on five different host plants.

Table 3 The mean values of reproduction parameters of *Helicoverpa armigera* on five different host plants.

Host plant	Gross fecundity rate (Eggs per female)	Gross fertility rate (Eggs per female)	Net fecundity rate (Eggs per female)	Net fertility rate (Eggs per female)
Cowpea	778.02	544.62	644.38	451.07
Soybean	1074.57	848.91	843.34	666.24
Corn	417.33	154.41	135.78	50.24
Navy bean	1173.64	809.81	862.25	594.95
Chickpea	1165.57	850.86	933.59	681.52

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Table 4 The mean (± SE) population parameters of *Helicoverpa armigera* on five different host plants.

Host plant	R_0 (female offspring per female)	r_m (day^{-1})	λ (day^{-1})	T (day)	DT (day)
Cowpea	365.66 ± 24.52a	0.180 ± 0.003a	1.192 ± 0.004a	31.62 ± 0.22c	3.92 ± 0.08b
Soybean	239.69 ± 14.74c	0.161 ± 0.004b	1.177 ± 0.004ab	33.28 ± 0.19b	4.23 ± 0.10b
Corn	147.40 ± 6.69d	0.126 ± 0.002c	1.131 ± 0.004c	37.90 ± 0.26a	5.62 ± 0.17a
Navy bean	294.28 ± 11.52b	0.164 ± 0.005b	1.178 ± 0.005ab	32.31 ± 0.71bc	4.14 ± 0.16b
Chickpea	359.67 ± 15.52a	0.161 ± 0.004b	1.175 ± 0.004b	33.28 ± 0.19b	4.27 ± 0.11b
F	22.01	15.35	17.83	28.49	21.54
df	4, 71	4, 94	4, 103	4, 103	4, 103
P	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means in a column followed by the same letter(s) are not significantly different (P < 0.05, Tukey's test).

Discussion

Host plants and diets taken from them may be different in terms of their nutritive properties and this difference may influence survival, development and reproductive rates of herbivorous insects feeding on them. Herbivorous insect pests usually have shorter development time and greater total reproduction on susceptible host plants in comparison with resistant ones. Such host plants can be rapidly colonized by insect pests (van Lenteren and Noldus, 1990). Although, developmental rates and reproduction provide clues concerning the ability of a host to support an insect to complete life cycle, these data should be linked to other parameters to show host suitability (Liu *et al.,* 2004). Results of the present study showed that the performance of the cotton bollworm differed significantly on the five host plants studied. It provided valuable information on the effect of different host plants on the performance of *H. armigera* which can be utilized properly in integrated pest management programs.

We found that the larvae reared on corn-based artificial diet moulted five times during their development time and had six larval instars similar to that reported previously by Ali *et al.* (2009) and Soleimannejad *et al.* (2010). Existence of different number of larval instars for the cotton bollworm shows that the number of larval instars in *H. armigera* can be affected by the quality of host plants. The results also revealed that the egg incubation period was not affected by host plant quality and *H. armigera* had the same incubation period on different host plants. In contrast with the incubation period, length of the larval stage and development time varied significantly on the different host plants and the longest larval period was observed on corn. This may stem from poor nutritional quality or existence of high amount of the secondary metabolites in this cultivar which makes it less suitable to be fed properly by *H. armigera*. Short life cycle, high reproductive potential and rapid population growth indicate suitability of a host plant to be colonized by an insect pest (Singh and Parihar, 1988). This would be reflected ultimately in the population size. These findings are in agreement with our previous outcomes (Baghery, 2011) in which we showed that the *H. armigera* feeding on corn had the lowest values of efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD). The value of ECD and ECI show the activity of digestive enzymes in an insect to utilize properly ingested food (Lazarevic *et al.,* 2004). Plants can synthesize the secondary substances that are involved in blocking of insects' digestive enzymes and can increase the resistance of host plants to insect pests (Chougule *et al.,* 2003). It seems that corn contains some enzyme inhibitors which can slow down the activity of digestive enzymes of *H. armigera* and prolong its developmental time.

Difference in the longevity of the cotton bollworm feeding on the five different host plants might have resulted due to the difference in the feeding rate or difference in the feeding efficiency of this pest in the larval stage on

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these host plants. When food quality decreases only a limited number of females are able to survive. The insufficient feeding in the larval stages may cause the number of eggs in the adult stage to decrease. This may explain the lower fecundity of *H. armigera* on the corn host plant compared with the others.

Our research demonstrated significant differences in the life table parameters of *H. armigera* on five different host plants studied. The lowest value of the net reproduction rate (147.40 ± 6.69 female offspring) was obtained on corn which was greater than that documented by Liu *et al.* (2004) on corn (44.5 female offspring) and similar to that reported by Reddy *et al.* (2004) on sunflower (143.77 female offspring). At the same time, Dabhi and Patel (2007) showed that the R_0 value of *H. armigera* on chickpea was 361.84 female offspring, which is close to our findings on chickpea in the present study, indicating the values of R_0 estimated in the current study were similar to those reported by other researchers (Dabhi and Patel, 2007). The net reproduction rate is an important parameter in population dynamics (Richard, 1961). Since this parameter indicates the physiological ability of an insect in relation to its reproductive capacity (Fathipour and Naseri, 2011), its comparison often provides considerable insight beyond that available from the independent analysis of individual life history parameters.

The intrinsic rate of increase is a key factor in the life table, influenced by different factors such as fecundity, survival and especially generation time. Furthermore, it adequately summarizes the physiological qualities of an insect to increase its population. Therefore, it would be a most appropriate index to evaluate the performance of an insect on different host plants or in other words it can show level of the resistance in different host plants to insect pests. Higher value of r_m on cowpea indicates that the cotton bollworm has a higher reproductive potential on this host plant. Similarly, lower value of r_m on corn can be attributed to its lower fecundity and longer development time on this host plant.

In cluster analysis, the groping of different host plants within the same cluster might be due to high correspondence of physiological traits of these host plants. In contrast, the separate clusters might represent significant variability in host plant suitability. By comparing the demographic parameters of *H. armigera* on five different host plants we found that the cluster A embraced highly susceptible host plants (cowpea and chickpea) whereas clusters B and C contained moderate (soybean and navy bean) and resistant (corn) host plants, respectively. The corn host plant grouped in cluster C and diverged from the others. It was the most resistant host plant to *H. armigera* because it retarded the development time of *H. armigera* and decreased its fecundity.

Our results confirmed the lower nutritional attribute of the corn host plant compared with the other species. Insufficient amount of primary metabolites necessary for growth and development of the cotton bollworm renders this host plant improper for *H. armigera*. Also, this plant may contain some phytochemicals that act as antixenosis and antibiosis agents, resulting in poor colonization of the cotton bollworm on this host plant. The antibiosis effects of this host plant may have led to the reduction in survival fitness of *H. armigera* and prolonged its development time. The increased development time of an insect pest can increase its exposure and predation by natural enemies. Understanding the extent of resistance in different host plants, population growth potential and biology of an insect pest on a host plant are important tools used in the integrated pest management (IPM) programs. It is known that the kind and amount of nutrients can affect the survival and reproduction of insect pests through targeting the capability of digestion and assimilation. Therefore, knowing how the quality of host plants influence the demographic parameters of *H. armigera* can help to increase our knowledge regarding its population dynamics and management. Our findings provided insights into the life cycle of *H. armigera* and its potential on different host plants. This information in combination with other semi-field and field experiments can be useful in development and implementation of management programs against *H. armigera*.

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رشدونمو، تولیدمثل و پارامترهای جدول زندگی *Helicoverpa armigera* (Lepidoptera: Noctuidae) روی بذر پنج میزبان مختلف گیاهی

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چکیده: کرم غوزه پنبه *Helicoverpa armigera* (Hübner) یکی از آفات مهم اقتصادی بسیاری از محصولات کشاورزی در بسیاری از مناطق دنیا است. در این تحقیق، پارامترهای دموگرافی این آفت روی بذر پنج میزبان گیاهی شامل لوبیا چشم بلبلی (رقم مشهد)، لوبیا سفید (رقم دهقان)، نخود (رقم هاشم)، سویا (رقم 033) و ذرت (رقم سینگل کراس 704) در شرایط آزمایشگاهی، دمای ۱ ± ۲۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۶۵ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی تعیین شد. کوتاه‌ترین طول دوره رشدی قبل از بلوغ ۳۶/۱۶ و ۳۴/۹۸ روز به‌ترتیب برای ماده و نر روی نخود بود و طولانی‌ترین مدت زمان این دوره برای نر و ماده روی ذرت بود (به‌ترتیب ۴۲/۰۰ و ۴۲/۹۵ روز). بیش‌ترین تخم‌ریزی روزانه و کل روی لوبیا چشم بلبلی و کم‌ترین آن روی ذرت مشاهده شد. براساس این نتایج، نرخ ذاتی افزایش جمعیت (r_m) روی میزبان‌های ذکر شده در بالا به‌ترتیب ۰/۱۸۰، ۰/۱۴۴، ۰/۱۶۱، ۰/۱۶۱ و ۰/۱۲۶ در روز و نرخ خالص تولیدمثل (R_0) روی این میزبان‌ها به‌ترتیب ۳۶۵/۶۶، ۲۹۴/۲۸، ۳۶۵/۶۷، ۲۳۹/۶۹ و ۱۴۷/۴۰ماده/ ماده بود. طولانی‌ترین متوسط مدت زمان یک نسل (T) و مدت زمان دو برابر شدن جمعیت (DT) این آفت به‌ترتیب ۳۷/۹۰ و ۵/۶۲ روز روی ذرت بود. این نتایج نشان داد در بین میزبان‌های گیاهی در این تحقیق لوبیا چشم بلبلی و ذرت به‌ترتیب حساس‌ترین و مقاوم‌ترین میزبان‌ها برای رشدونمو *H. armigera* بودند.

واژگان کلیدی: کرم غوزه پنبه، *Helicoverpa armigera*، باروری، ذرت (cv. Single cross 704)، لوبیا چشم بلبلی (cv. Mashhad)

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