

Research Article

## Demographic parameters of *Helicoverpa armigera* on ten corn hybrids-mediated artificial diets reveals striking differences

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**Abstract:** The cotton bollworm, *Helicoverpa armigera* (Hübner), is a destructive pest feeding on a diverse array of host plants. We studied the demographic parameters of *H. armigera* on artificial diets prepared from seeds of 10 corn *Zea mays* L. hybrids (KSC301, KSC403, KSC540, KSC600, KSC604, KSC704, KSC711, Maxima, NS770, and ZP677) using the age-stage, two-sex life table procedure. The results revealed that except for the incubation period, the *Z. mays* hybrids-mediated artificial diets significantly affected the length of the other immature stages. They also influenced the adult longevity, adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), and oviposition days of *H. armigera*. Furthermore, the total fecundity of *H. armigera* was affected by *Z. mays* hybrids. Accordingly, the females reared on KSC711 with 503.31 eggs had the highest total fecundity. The highest net reproductive rate ( $R_0$ ) (88.41 eggs/individual), the intrinsic rate of increase ( $r$ ) ( $0.109 \text{ day}^{-1}$ ), and finite rate of increase ( $\lambda$ ) ( $1.115 \text{ day}^{-1}$ ) were observed on KSC711. Our results provided valuable information regarding the life cycle of *H. armigera* on an artificial diet substrate prepared from different *Z. mays* hybrids. It was also revealed that although *H. armigera* had no significant differences in life table parameters on most hybrids, some of them, such as KSC711, were very susceptible to damage. One of the issues that emerged from these findings is the possibility of using some hybrids, e.g., KSC711, in the preparation of semi-artificial diets for this pest.

**Keywords:** artificial diet, life table parameter, nutritional quality, secondary metabolites, seed-based diets

### Introduction

The cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), is a highly cosmopolitan and destructive pest feeding on 170 plant species (Zalucki *et al.*, 1994), including

cotton, maize, chickpea, pigeon pea, sorghum (Fitt, 1989), tomato (Garcia, 2006) and soybean (Naseri *et al.*, 2009a). Although the neonate larvae feed on different parts of host plants such as flower, bud, stem, and leaves, its larvae prefer plant's reproductive organs (Zalucki *et al.*, 1986; Fitt, 1989; Garcia 2006). Therefore, larvae can cause irreparable damage to plants. Polyphagy, high mobility, high fecundity, and facultative diapause enable this pest to survive in various habitats (Fitt, 1989) and make it difficult to manage. Since chemical control cannot be a

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permanent tool for the management of *H. armigera*, the demand for effective and low-risk methods is growing rapidly (Bagheri *et al.*, 2019). The high potential profit margin has also encouraged farmers to move towards pesticide-free management methods (Jha *et al.*, 2012). The use of genetically resistant hostplants is one of the most widely used methods to diminish this pest's damage (Fathipour *et al.*, 2020). Also, it can be integrated successfully with other non-chemical managing approaches. In cases where chemical toxins are inevitable, using resistant varieties can provide conditions for the simultaneous use of light spraying and natural enemies.

Demographic parameters provide a simple way to extract detailed information about an insect pest's population growth potential in the current and the next generations (Frei *et al.*, 2003). It is a powerful tool to analyze and understand the effect of external factors and host plants on the growth, survival, reproduction, and intrinsic rate of increase of insect populations (Chi and Su, 2006). Such information can be adequately utilized in integrated pest management (IPM) programs. The study of demography based on a seed-based artificial diet is a cost-effective approach that has been widely used for different insect species (Soleimannejad *et al.*, 2010; Mortazavi *et al.*, 2015). Because any plant seed is an embryonic plant enclosed in a protective outer covering (Yang and Lee, 2014), and by studying them, we can find valuable information about their resistance which can be extended to the plants grown from these seeds. Besides, plant seeds may have several secondary substances (Quiróz-Sodi *et al.*, 2018) and are similar to plant foliage in terms of resistance. These compounds can positively or negatively affect insect pests' feeding behavior (Singh and Parihar 1988) by targeting their development time, survival rate, reproduction, and life table parameters (Soufbaf *et al.*, 2012). In addition to the priorities mentioned above, studying insect's demographic parameters on diets prepared from plant seeds makes it possible to use them in rearing insects. Since rearing insects on semi-artificial diets is an expensive process, finding the economically high potent diets helps us rear

key insect pests to study their life table, behavior, development, physiology, biological control agents, and response to chemical pesticides (Fallahnejad-Mojarrad *et al.*, 2018).

Although, numerous research works have studied the demographic parameters of *H. armigera* under varying conditions, e.g., constant and alternating temperatures (Mironidis and Savopoulou-Soultani, 2008) and different host plants (e.g., Liu *et al.*, 2004; Naseri *et al.*, 2009a b; Karimi *et al.*, 2012; Safuraie-Parizi *et al.*, 2014; Fallahnejad-Mojarrad *et al.*, 2018), there are still many questions about its damaging behavior on unstudied host plants or their seed-based diets. Furthermore, a part of the research on *H. armigera* is based on the age-specific female life table (Naseri *et al.*, 2009 b; Soleimannejad *et al.*, 2010; Karimi *et al.*, 2012) that ignores the overlap of developmental stages in *H. armigera* populations or calculates age-specific fecundity based on the adult age. It has been revealed that extending the results of an age-specific female life table to a two-sex population may reshape the relationship between gross reproductive rate, net reproductive rate, and preadult survivorship (Yu *et al.*, 2005). A two-sex life table procedure has been shown to resolve this problem using the age stage. Here, we aimed to study the demographic parameters of *H. armigera* on artificial diets prepared from seeds of 10 *Zea mays* L. hybrids using the age-stage, two-sex life table procedure and compare the results with those inferred from age-specific female life table on the same host plant or different host plant species.

## Materials and Methods

### Plant seeds

The seeds of 10 *Z. mays* hybrids (KSC301, KSC403, KSC540, KSC600, KSC604, KSC704, KSC711, Maxima, NS770, and ZP677) were prepared from Seed and Plant Improvement Institute, Karaj, Iran.

### Rearing methods and experimental conditions

The stock population of *H. armigera* was provided by the University of Tabriz (Iran) and kept on an artificial diet (based on cowpea

powder) for two generations, and the eggs of the third generation were used in the experiments. The primary source of this line was naturally infested fields of Parsabad-Moghan, Ardabil province (Iran). Before the experiments, the insects were reared for two generations on an artificial diet prepared from cowpea seeds. The demographic parameters were then studied on eggs laid by the second generation of the laboratory insects. The rearing was performed in a growth chamber set at  $25 \pm 1$  °C,  $65 \pm 5\%$  RH, and a photoperiod of 16: 8 (L: D) hours.

The artificial diets were prepared as follows: the powdered seed of each corn hybrid (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-hydroxybenzoate (2.2 g), formaldehyde 37% (2.5 g), and distilled water (650 ml) (Teakle, 1991).

First, it was attempted to establish a colony of *H. armigera* on each *Z. mays* hybrid from the egg stage. Since some of the emerged females were sterile or produced infertile eggs, the experiment was initiated with the same aged eggs produced by insects feeding on an artificial diet prepared from cowpea. To this end, and for each hybrid, ten pairs of moths (both sexes) (< 24 h old) reared on a diet mentioned above 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. *Helicoverpa armigera* adults were provided with diluted honey (10%) on cotton rolls during oviposition. The eggs laid on the net were harvested for running the experiment.

#### Determining demographic parameters

At least-100 same-aged eggs were used to study the demographic parameters of *H. armigera*. All eggs were checked daily, and the newly hatched larvae were transferred individually into plastic containers using a fine camel hairbrush. The plastic containers were 5 cm in diameter and 3 cm in height, with a hole covered by a fine mesh net for ventilation. A 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 the presence of exuviae from molting. The fifth instar larvae were kept in the plastic containers for pre-pupation and pupation. The pupae were also checked daily until all adults emerged or the pupae died. At pupation, the individuals were sexed (the female genital opening or suture is located in the middle of the 8<sup>th</sup> abdominal segment, whereas the male genital opening is shown at the 9<sup>th</sup> abdominal segment). After adults' emergence, a pair of female and male moths were transferred into the oviposition cages (11 cm in diameter and 12 cm in height). The adults were supplied using a small cotton wick soaked in 10% honey solution placed daily in the oviposition cages. The adults were introduced into new oviposition cages daily, and the laid eggs were counted and harvested once a day. The adult longevity, oviposition days, and fecundity were determined on the artificial diets until the last individual's death.

The data gathered from the life history of all individuals were analyzed according to the age-stage, two-sex life table procedure (Chi and Liu, 1985; Chi, 1988) using the TWSEX-MSChart program (Chi, 2019). The age-stage-specific survival rate ( $s_{xj}$ ) (where  $x$  = age in days and  $j$  = stage); the age-stage-specific fecundity ( $f_{xj}$ ); the age-specific survivorship ( $l_x$ ); the age-specific fecundity ( $m_x$ ); and the population growth parameters (intrinsic rate of increase ( $r$ ); finite rate of increase ( $\lambda$ ); net reproductive rate ( $R_0$ ), and mean generation time ( $T$ )) were calculated. All of the standard errors were estimated by the bootstrap technique with 100,000 bootstraps and then used the paired bootstrap test to compare the differences among hybrids.

## Results

### Development of immature stages

The effects of different *Z. mays* hybrids on the development time of *H. armigera* are shown in Table 1. Except for the incubation period, the *Z. mays* hybrids significantly affected the length of the other immature stages. Accordingly, the

longest larval period was observed on KSC600 without significant differences with KSC301, KSC540, and KSC704. However, the shortest larval duration was on KSC711 (Table 1). Except for KSC604 and KSC711 (without significant difference with Maxima), most hybrids had no significant pupal stage length differences (Table 1). The length of preadult and total life span (from egg to death of adult) of *H. armigera* were also affected by different *Z. mays* hybrids. Accordingly, the larva reared on KSC600 and KSC540 had the longest preadult and total life span (without significant differences with KSC704). However, the shortest preadult duration was observed on KSC711 and Maxima, and the larvae reared on KSC604 and Maxima had the shortest total life span (Table 1).

#### Adult longevity and fecundity

Adult longevity of *H. armigera* was significantly affected by different *Z. mays* hybrids. The most prolonged adult longevity was observed on KSC711, and the shortest one was on KSC301 (without significant difference with KSC604, KSC600, and Maxima) (Table 1). The *Z. mays* hybrids significantly affected the adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), and oviposition days of *H. armigera*. The longest APOP was observed on Maxima, and the shortest one was on KSC301 and

KSC604. The longest TPOP was observed on KSC301 and KSC600 that had no significant differences with KSC540. The shortest TPOP was on KSC604. Although the insects reared on KSC711 had the longest oviposition days, this hybrid had no significant differences with KSC704, KSC540, and KSC600. However, the shortest oviposition days were observed in those larvae reared on Maxima (without significant differences with KSC604, KSC301, and NS770) (Table 1). The total fecundity of *H. armigera* was also affected by *Z. mays* hybrids. Accordingly, the females reared on KSC711 had the highest total fecundity (Table 1).

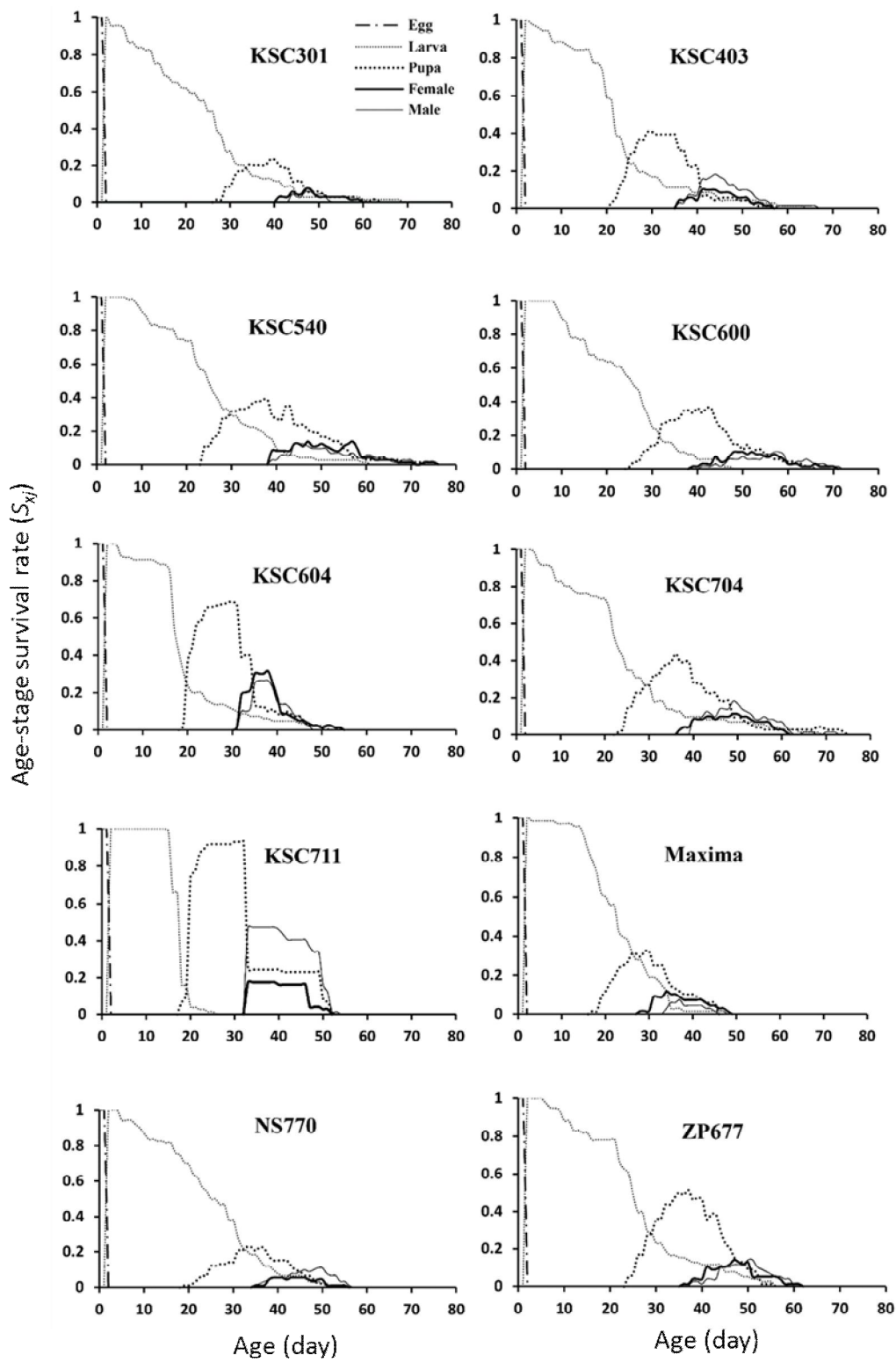
#### The survival rate, age-specific fecundity

The curves of age-stage survival rate ( $s_{xj}$ ) show the probability that a newborn individual survives to age  $x$  and stage  $j$ . The curves depict the detailed survival and stage differentiation process of the cohort. The curves of age-stage survival rate ( $s_{xj}$ ) showing the survival probability in different stages of *H. armigera* reared on *Z. mays* hybrids are plotted in Fig. 1. The probability that a newborn egg survives to the adult stage was 0.78, 0.33, 0.43, 0.44, 0.23, 0.61, 0.33, 0.38, 0.89 and 0.51 by feeding on KSC604, KSC600, KSC540, KSC403, KSC301, ZP677, NS770, Maxima, KSC711, and KSC704, respectively.

**Table 1** Mean ( $\pm$  SE) duration of different life stages and fecundity of *Helicoverpa armigera* emerging from larvae reared on different *Zea mays* hybrids-mediated artificial diet.

Parameter	KSC301	KSC403	KSC540	KSC600	KSC604	KSC704	KSC711	Maxima	NS770	ZP677
Egg	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>	2.00 $\pm$ 0.000 <sup>a</sup>
Larva	28.90 $\pm$ 1.670 <sup>ab</sup>	22.48 $\pm$ 0.911 <sup>c</sup>	28.10 $\pm$ 1.370 <sup>ab</sup>	30.15 $\pm$ 1.160 <sup>a</sup>	18.32 $\pm$ 0.772 <sup>d</sup>	29.52 $\pm$ 1.850 <sup>ab</sup>	15.71 $\pm$ 0.202 <sup>e</sup>	20.53 $\pm$ 0.924 <sup>cd</sup>	25.80 $\pm$ 0.882 <sup>b</sup>	26.00 $\pm$ 0.807 <sup>b</sup>
Pre Pupa	3.40 $\pm$ 0.310 <sup>a</sup>	3.03 $\pm$ 0.224 <sup>ab</sup>	2.80 $\pm$ 0.155 <sup>ab</sup>	2.85 $\pm$ 0.230 <sup>ab</sup>	2.84 $\pm$ 0.100 <sup>ab</sup>	3.17 $\pm$ 0.207 <sup>a</sup>	2.76 $\pm$ 0.125 <sup>ab</sup>	3.17 $\pm$ 0.240 <sup>a</sup>	3.08 $\pm$ 0.320 <sup>ab</sup>	2.57 $\pm$ 0.142 <sup>b</sup>
Pupa	14.25 $\pm$ 0.344 <sup>abc</sup>	14.62 $\pm$ 0.280 <sup>ab</sup>	14.54 $\pm$ 0.245 <sup>ab</sup>	14.55 $\pm$ 0.240 <sup>ab</sup>	13.06 $\pm$ 0.137 <sup>d</sup>	14.15 $\pm$ 0.210 <sup>bc</sup>	13.06 $\pm$ 0.137 <sup>d</sup>	13.41 $\pm$ 0.463 <sup>cd</sup>	14.14 $\pm$ 0.294 <sup>abc</sup>	15.00 $\pm$ 0.306 <sup>a</sup>
Pre-adult	45.17 $\pm$ 0.860 <sup>bc</sup>	41.17 $\pm$ 1.073 <sup>d</sup>	48.03 $\pm$ 1.540 <sup>ab</sup>	49.66 $\pm$ 1.355 <sup>a</sup>	34.83 $\pm$ 0.553 <sup>e</sup>	46.18 $\pm$ 1.320 <sup>abc</sup>	33.00 $\pm$ 0.000 <sup>f</sup>	34.60 $\pm$ 1.010 <sup>ef</sup>	42.00 $\pm$ 1.076 <sup>d</sup>	43.73 $\pm$ 0.792 <sup>cd</sup>
APOP	3.66 $\pm$ 0.820 <sup>e</sup>	4.83 $\pm$ 1.153 <sup>bc</sup>	4.91 $\pm$ 0.693 <sup>bc</sup>	4.50 $\pm$ 1.071 <sup>bc</sup>	3.70 $\pm$ 0.240 <sup>f</sup>	4.75 $\pm$ 0.520 <sup>bc</sup>	5.46 $\pm$ 0.268 <sup>b</sup>	9.60 $\pm$ 1.303 <sup>a</sup>	0.00 $\pm$ 0.000 <sup>g</sup>	4.62 $\pm$ 0.630 <sup>bc</sup>
TPOP	49.66 $\pm$ 1.724 <sup>a</sup>	43.66 $\pm$ 1.100 <sup>e</sup>	49.00 $\pm$ 2.323 <sup>ab</sup>	55.38 $\pm$ 2.821 <sup>a</sup>	36.35 $\pm$ 0.317 <sup>e</sup>	48.00 $\pm$ 1.440 <sup>b</sup>	38.46 $\pm$ 0.268 <sup>d</sup>	40.00 $\pm$ 1.010 <sup>d</sup>	40.00 $\pm$ 1.762 <sup>cd</sup>	48.25 $\pm$ 1.755 <sup>b</sup>
Oviposition days	2.00 $\pm$ 0.310 <sup>cd</sup>	2.50 $\pm$ 0.730 <sup>bcd</sup>	3.27 $\pm$ 0.470 <sup>ab</sup>	3.00 $\pm$ 0.735 <sup>abc</sup>	2.00 $\pm$ 0.226 <sup>cd</sup>	3.42 $\pm$ 0.431 <sup>ab</sup>	4.31 $\pm$ 0.441 <sup>a</sup>	1.40 $\pm$ 0.246 <sup>d</sup>	2.00 $\pm$ 0.930 <sup>bd</sup>	2.38 $\pm$ 0.600 <sup>bcd</sup>
Fecundity	64.86 $\pm$ 55.500 <sup>bc</sup>	55.00 $\pm$ 41.127 <sup>bc</sup>	166.16 $\pm$ 55.224 <sup>b</sup>	155.66 $\pm$ 59.070 <sup>b</sup>	100.90 $\pm$ 28.626 <sup>b</sup>	175.33 $\pm$ 51.631 <sup>b</sup>	503.31 $\pm$ 137.30 <sup>a</sup>	80.70 $\pm$ 37.460 <sup>bc</sup>	61.00 $\pm$ 27.721 <sup>bc</sup>	24.26 $\pm$ 13.370 <sup>c</sup>
Adult longevity	5.93 $\pm$ 0.701 <sup>c</sup>	10.13 $\pm$ 0.905 <sup>b</sup>	9.63 $\pm$ 0.740 <sup>bc</sup>	7.74 $\pm$ 0.750 <sup>abc</sup>	7.50 $\pm$ 0.422 <sup>bc</sup>	9.02 $\pm$ 0.633 <sup>bc</sup>	15.60 $\pm$ 0.500 <sup>a</sup>	7.43 $\pm$ 1.23 <sup>abc</sup>	8.64 $\pm$ 0.970 <sup>bcd</sup>	8.53 $\pm$ 0.773 <sup>bcd</sup>
Total life span	51.08 $\pm$ 1.233 <sup>cd</sup>	51.30 $\pm$ 1.120 <sup>d</sup>	57.66 $\pm$ 1.343 <sup>a</sup>	57.41 $\pm$ 1.570 <sup>a</sup>	42.35 $\pm$ 0.550 <sup>f</sup>	55.20 $\pm$ 1.166 <sup>ab</sup>	48.60 $\pm$ 0.500 <sup>d</sup>	42.00 $\pm$ 1.063 <sup>e</sup>	50.64 $\pm$ 0.943 <sup>cd</sup>	52.26 $\pm$ 1.032 <sup>bc</sup>

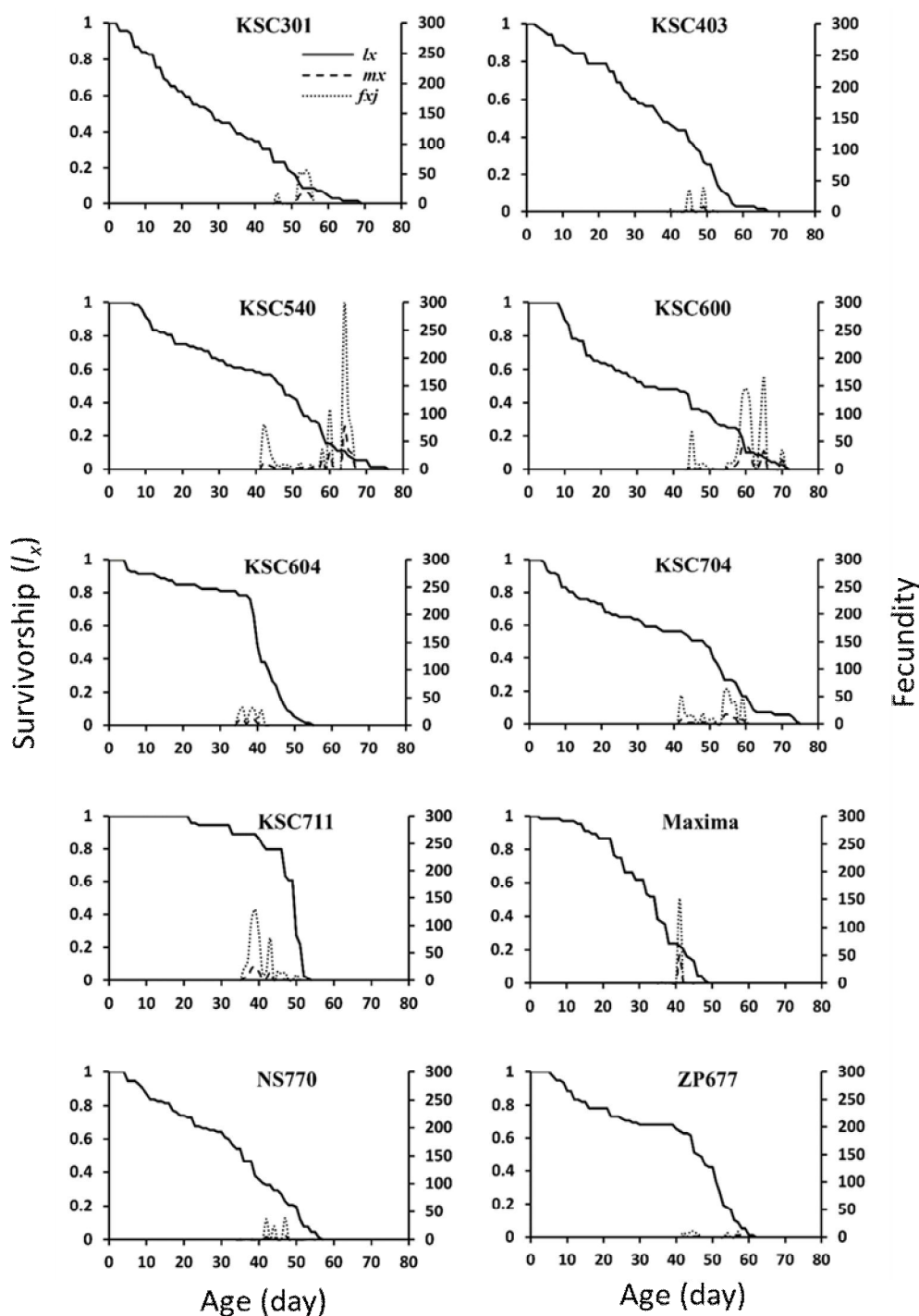
The means followed by the same letters in each row are not significantly different ( $P < 0.05$ , Paired bootstrap test). APOP, adult pre-ovipositional period; TPOP, Total pre-ovipositional period (from egg to first oviposition).



**Figure 1** Age-stage survival rate ( $s_{xj}$ ) of *Helicoverpa armigera* emerging from larvae reared on different *Zea mays* hybrids-mediated artificial diet.

The age-stage-specific fecundity ( $f_{xj}$ ) presents the mean number of offspring produced by the adult females at age  $x$  and

stage  $j$  and, because only females produced eggs, there was only a single curve  $f_{xj}$  ( $x$ , female) (Fig. 2).



**Figure 2** Age-specific survivorship ( $l_x$ ), age-stage specific fecundity ( $f_{xj}$ ), and age-specific fecundity ( $m_x$ ) of *Helicoverpa armigera* emerging from larvae reared on different *Zea mays* hybrids-mediated.

The start of oviposition of the first female on KSC604, KSC600, KSC540, KSC403, KSC301, ZP677, NS770, Maxima, KSC711, and KSC704 occurred at the age of 35, 44, 42, 40, 46, 42, 35, 36, 36, and 42 days, respectively. In addition, the highest daily fecundity (peak of  $f(i, \text{female})$ ) of *H. armigera* on KSC604, KSC600, KSC540, KSC403, KSC301, ZP677, NS770, Maxima, KSC711, and KSC704 was 31.46, 166, 303.5, 38.5, 56, 11.38, 38.25, 152.2, 129.08, and 63.4 eggs, which occurred at the age of 36, 65, 64, 49, 54, 44, 47, 41, 39, and 55 days, respectively. The difference in females' daily fecundity reared on ten different *Z. mays* hybrids is represented in the age-specific fecundity curve ( $m_x$ ) (Fig. 2). The adults of *H. armigera* mated after emergence, and the mated females on KSC604 started to oviposit before others at the age of 35 d. The fecundity curve ended after others at the age of 42 d on the same hybrid. When *H. armigera* were reared on NS770 and ZP677, the  $m_x$  curves were low, mostly < 10 eggs per day, while most individuals reared on KSC540

and KSC600 could lay up to 75 and 41 eggs per day, respectively (with the longest range of  $m_x$ ) (Fig. 2).

### Life table parameters

The population (life table) parameters of *H. armigera* on the different *Z. mays* hybrids-mediated artificial diet were calculated based on the entire cohort's data and are presented in Table 2. The highest net reproductive rate ( $R_0$ ) was observed on KSC711 and KSC604. These hybrids both had no significant differences with KSC540, KSC704, and KSC600. The lowest values of  $R_0$  were on NS770 that had no significant differences with ZP677, KSC403, KSC301, and Maxima. Different *Z. mays* hybrids had substantial differences in terms of the intrinsic rate of increase ( $r$ ) and finite rate of increase ( $\lambda$ ), ranging from 0.109 day<sup>-1</sup> and 1.115 day<sup>-1</sup> on KSC711 to 0.028 day<sup>-1</sup> and 1.029 day<sup>-1</sup> on ZP677, respectively. The mean generation time ( $T$ ) varied from 57.50 days on KSC600 to 38.27 days on KSC604.

**Table 2** Age-stage, two-sex life table parameters (Mean  $\pm$  SE) of *Helicoverpa armigera* emerging from larvae reared on different *Zea mays* hybrids-mediated artificial diet.

Parameter	KSC301	KSC403	KSC540	KSC600	KSC604	KSC704	KSC711	Maxima	NS770	ZP677
$GRR$ (eggs/individual)	68.80 $\pm$ 62.056 <sup>abc</sup> (65.70)	18.70 $\pm$ 13.980 <sup>bc</sup> (18.71)	229.80 $\pm$ 114.094 <sup>abc</sup> (230.51)	235.93 $\pm$ 105.520 <sup>b</sup> (238.40)	57.75 $\pm$ 18.711 <sup>ab</sup> (57.74)	89.81 $\pm$ 39.264 <sup>abc</sup> (89.75)	103.44 $\pm$ 37.105 <sup>b</sup> (103.45)	54.00 $\pm$ 26.619 <sup>abc</sup> (53.80)	17.06 $\pm$ 9.358 <sup>bc</sup> (17.05)	13.48 $\pm$ 6.801 <sup>c</sup> (13.52)
$R_0$ (eggs/individual)	6.88 $\pm$ 5.713 <sup>abc</sup> (6.58)	6.19 $\pm$ 4.776 <sup>abc</sup> (6.20)	43.85 $\pm$ 16.665 <sup>ab</sup> (43.85)	33.91 $\pm$ 14.695 <sup>abcd</sup> (33.84)	39.60 $\pm$ 12.420 <sup>b</sup> (39.58)	29.64 $\pm$ 11.458 <sup>abc</sup> (29.63)	88.41 $\pm$ 32.140 <sup>a</sup> (88.42)	11.92 $\pm$ 6.283 <sup>abc</sup> (11.87)	4.64 $\pm$ 2.569 <sup>f</sup> (4.64)	4.66 $\pm$ 2.729 <sup>bc</sup> (4.66)
$r$ (day <sup>-1</sup> )	0.024 $\pm$ 0.028 <sup>cd</sup> (0.035)	0.028 $\pm$ 0.026 <sup>cd</sup> (0.039)	0.072 $\pm$ 0.010 <sup>bc</sup> (0.073)	0.059 $\pm$ 0.010 <sup>cd</sup> (0.061)	0.095 $\pm$ 0.009 <sup>ab</sup> (0.096)	0.066 $\pm$ 0.008 <sup>f</sup> (0.067)	0.109 $\pm$ 0.010 <sup>a</sup> (0.111)	0.054 $\pm$ 0.018 <sup>cd</sup> (0.059)	0.029 $\pm$ 0.020 <sup>cd</sup> (0.034)	0.028 $\pm$ 0.016 <sup>d</sup> (0.033)
$\lambda$ (day <sup>-1</sup> )	1.024 $\pm$ 0.028 <sup>f</sup> (1.036)	1.029 $\pm$ 0.026 <sup>cc</sup> (1.039)	1.074 $\pm$ 0.010 <sup>bc</sup> (1.076)	1.061 $\pm$ 0.010 <sup>abc</sup> (1.063)	1.099 $\pm$ 0.010 <sup>ab</sup> (1.100)	1.068 $\pm$ 0.009 <sup>cd</sup> (1.069)	1.115 $\pm$ 0.011 <sup>a</sup> (1.117)	1.056 $\pm$ 0.019 <sup>abc</sup> (1.060)	1.029 $\pm$ 0.020 <sup>abc</sup> (1.034)	1.029 $\pm$ 0.017 <sup>cc</sup> (1.033)
$T$ (day)	51.99 $\pm$ 2.777 <sup>bb</sup> (53.48)	47.19 $\pm$ 1.361 <sup>bc</sup> (47.24)	51.84 $\pm$ 3.894 <sup>abc</sup> (51.45)	57.50 $\pm$ 3.137 <sup>a</sup> (57.27)	38.27 $\pm$ 0.435 <sup>f</sup> (38.27)	50.47 $\pm$ 2.404 <sup>abc</sup> (50.46)	40.55 $\pm$ 0.389 <sup>f</sup> (40.49)	41.90 $\pm$ 0.548 <sup>d</sup> (41.98)	45.20 $\pm$ 1.382 <sup>c</sup> (45.26)	47.98 $\pm$ 2.769 <sup>bc</sup> (46.98)

Data in the first row for each parameter is the mean of the bootstrap samples (100,000), and data in the parenthesis are the original values of the parameters. Each row followed by different letter(s) is significantly different ( $P < 0.05$ ; Paired bootstrap test).

### Discussion

Seed-based diets may be different in terms of nutritional quality, and these differences may affect the survival, development, and population parameters of pests feeding on them (Fischer et al., 2008; Shelat et al., 2019). Herbivorous insects usually have a short development time and high population parameters on susceptible hosts. Thereby, they

are rapidly colonized by insect pests (van Lenteren and Noldus, 1990). Development rates and growth parameters can provide clues concerning a host's ability to supply the insects with nutrients needed to complete life cycles (Liu et al., 2004).

*Helicoverpa armigera* had the same incubation period on all *Z. mays* hybrids. All the eggs harvested from females were reared on cowpea before oviposition so that the females

would be in identical nutritional conditions for egg-laying. Lack or low feeding of females on a host plant can fade host plants' effects on the incubation period. By contrast, different *Z. mays* hybrids affected the length of the other immature stages (e.g., larva, pre-pupa, and pupa). They also changed the development time and total life span of *H. armigera*. KSC711 had the shortest larval duration, most likely due to its high nutritional quality, making it suitable for feeding (see Soleimannejad *et al.*, 2010). In other words, the lack or low rate of secondary metabolites is another possibility to explain this issue. Short life cycle, high fecundity, and rapid population growth parameters show the suitability of a seed-based diet or a host plant to be colonized rapidly by insect pests (Singh and Parihar, 1988; Fallahnejad-Mojarrad *et al.*, 2018). Suitability of diet would be ultimately reflected in the population size. The *Z. mays* hybrids also affected the length of pre-pupal and pupal stages. These findings are consistent with the results of Safuraie-Parizi *et al.* (2014), who showed the effects of different tomato varieties on the pupal period of *H. armigera*. However, they reported a shorter pupal period (10.53-13.00 days on tomato) than those we obtained on *Z. mays* hybrids. Proper feeding on high-quality hosts with low secondary metabolites can give rise to high-weight pupa with shorter pupal duration (Soleimannejad *et al.*, 2010).

The *Z. mays* hybrids may possess a lower nutrient content or a higher rate of secondary substances than tomato, making them unsuitable for feeding (Fallahnejad-Mojarrad *et al.*, 2018). Plants can synthesize secondary substances that contribute to blocking the insect's digestive enzymes and increasing the host plant resistance (Chougule *et al.*, 2003). Here, these compounds may slow down the activity of digestive enzymes and prolong the developmental time of *H. armigera*. Also, in the lack of high-quality hosts, only a limited number of female individuals can survive. This property may explain the lower fecundity of *H. armigera* on the hybrids that prolonged the larval stage.

Our study demonstrated significant differences in the life table parameters of *H. armigera* on the

studied hybrids. We found high variation in the values of net reproductive rate on the *Z. mays* hybrids, ranging from  $4.64 \pm 2.57$  eggs/individual to  $88.41 \pm 32.14$  eggs/individuals. Although there were similarities between our results and other researchers (Liu *et al.*, 2004), they do not support the findings of Patal and Koshyia (1997), Reddy *et al.* (2004), Naseri *et al.* (2009a, b), and Karimi *et al.* (2012). The genetic pattern of host plants and pests and the differences in the experimental conditions may explain these contradictions. The net reproductive rate is an essential parameter in population dynamics (Richard, 1961). It indicates an insect's physiological ability concerning its reproductive capacity; therefore, its comparison often provides considerable insights beyond whatever could be available from the independent analysis of individual life-history parameters.

Likewise,  $R_0$ , the values of  $r$  showed high variations on the different *Z. mays* hybrids. The highest and lowest values of  $r$  were observed on KSC711 and ZP677, respectively. In other words, *H. armigera* had the highest and lowest population growth potential on these hybrids. Any reduction in host plants' nutritional quality will translate into a decrease in egg-laying and increased development time, affecting the  $r$ -value. The finite rate of increase ( $\lambda$ ) followed the same pattern as the intrinsic rate of increase on different *Z. mays* hybrids. Therefore, all probabilities discussed for the high variation in the net reproduction rate values on different *Z. mays* hybrids can be extended to both of these two parameters. The intrinsic rate of increase is a key factor in the life table, influenced by numerous factors such as pests and host plant genetic patterns. Furthermore, it adequately summarizes the physiological qualities of an insect to increase its population. Therefore, it would be a most appropriate index to evaluate an insect pest's performance on different host plants, or in other words, it can show the level of the resistance in different host plants.

Although in this study we focused on the resistance potential of the different *Z. mays* hybrids to *H. armigera*, the results showed that some hybrids, e.g., KSC711, may be valuable in the preparation of semi-artificial diets. Because the



cotton bollworm completed its life cycle on this hybrid quicker than the other hybrids and thereby had the higher life table parameters. During the last decade, several studies have been conducted on the effects of various semi-artificial diets on the life table parameters of *H. armigera*, in which efforts have been made to introduce economic and high-quality diets (Soleimannejad et al., 2010; Fallahnejad-Mojarrad et al., 2018). The findings of the present study on seed-based diets will help us choose an appropriate artificial diet for mass rearing of *H. armigera* in the controlled conditions to use them in different experiments.

### Conclusion

Our findings provided valuable information regarding the life cycle of *H. armigera* on an artificial diet substrate prepared from different *Z. mays* hybrids. Furthermore, it was revealed although most hybrids had no significant differences in terms of resistance to *H. armigera*, some of them were highly susceptible. However, this research has put forth many questions that need further investigation, e. g., interactions between primary and secondary compounds, the role of seed-associated microorganism (endophytes) in the production of secondary metabolites in the resistant hybrids, and the possibility of their transmission to the susceptible ones using inoculation or genetic engineering. The compatibility of resistant hybrids with other managing tactics is another critical issue that needs to be answered. Finally, by examining the plants from these seeds in greenhouse or field conditions, we could answer whether it is possible to determine plants' susceptibility or resistance based on seeds.

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### Author statement

All authors compiled, wrote, and approved this research article.

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## پارامترهای دموگرافیک کرم غوزه پنبه *Helicoverpa armigera* روی غذاهای مصنوعی تهیه شده از هیبریدهای ذرت تفاوت‌های چشم‌گیری نشان می‌دهند

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**چکیده:** کرم غوزه پنبه (*Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)) یکی از آفات بسیار خطرناک است که از مجموعه متنوعی از گونه‌های گیاهی تغذیه می‌کند. در پژوهش حاضر، پارامترهای دموگرافیک کرم غوزه پنبه روی رژیم غذایی مصنوعی تهیه شده از بذرها ۱۰ هیبرید ذرت با استفاده از روش جدول زندگی دوجنسی بررسی شد. تمامی آزمایش‌ها در شرایط آزمایشگاهی در دمای  $25 \pm 1$  درجه سلسیوس، رطوبت نسبی  $65 \pm 5$  درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی انجام شد. نتایج به‌دست آمده نشان داد که به‌جز دوره جنینی، تغذیه از غذای مصنوعی روی طول سایر مراحل نابالغ تأثیرگذار بود. همچنین اثر هیبریدهای مختلف ذرت روی طول عمر افراد بالغ، میانگین طول دوره قبل از تخم‌ریزی افراد بالغ (APOP)، میانگین کل دوره قبل از تخم‌ریزی (TPOP)، طول دوره تخم‌گذاری و باروری کل در کرم غوزه پنبه معنی‌دار بود. براساس نتایج به‌دست آمده، ماده‌های پرورش یافته روی KSC711 با  $50.3/31$  عدد تخم دارای بیش‌ترین میزان باروری کل بودند. بیش‌ترین مقدار نرخ خالص تولیدمثل ( $R_0$ )  $88/41$  تخم به‌ازای هر فرد، نرخ ذاتی افزایش جمعیت ( $r$ )  $0/109$  بر روز و نرخ متنهای افزایش جمعیت ( $\lambda$ )  $1/115$  بر روز در KSC711 مشاهده شد. نتایج پژوهش حاضر، حاوی اطلاعات ارزشمندی درخصوص چرخه زندگی کرم غوزه پنبه روی رژیم غذایی مصنوعی تهیه شده از هیبریدهای مختلف ذرت است. در مجموع، گرچه تفاوت معنی‌داری در پارامترهای دموگرافیک کرم غوزه پنبه روی اکثر هیبریدهای مورد مطالعه مشاهده نشد ولی مشخص شد که این آفت روی برخی از هیبریدها مانند KSC711 پارامترهای رشدی بالاتری داشت که نشان از حساسیت بالای این هیبرید دارد. با توجه به اطلاعات موجود، KSC711 می‌تواند یک گزینه مناسب برای تهیه غذایی نیمه مصنوعی برای کرم غوزه پنبه باشد.

**واژگان کلیدی:** غذای مصنوعی، پارامتر جدول زندگی، کیفیت تغذیه‌ای، متابولیت‌های ثانویه، رژیم غذایی تهیه شده از بذر