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Demographic Comparison of *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) Reared on Different Potato Cultivars

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ABSTRACT

Potato Tuber Moth (PTM), *Phthorimaea operculella* (Zeller), is one of the most destructive pests of potatoes under field and storage conditions. Exploiting plant resistance may help control the pest in an eco-friendly manner. Therefore, the present study aimed to assess the resistance status of six common potato cultivars (Banba, Bellini, Draga, Marfona, Jelly, and Milva) under laboratory conditions (25±1°C, 65±5% RH and 14:10 (L: D) hours photoperiod). Life history and demographic parameters of *P. operculella* under laboratory conditions were analyzed based on the age-stage, two-sex life table theory, which could be appropriate indices in resistance and susceptibility evaluation of potato cultivars. Pre-adult development was slower on Marfona and faster on Banba (19.91 and 21.93 days, respectively) compared to the other cultivars. The longest oviposition days was found on Jelly (8.20 days), while the shortest (5.43 days) was on Bellini. The maximum values of *r* and λ were found on Marfona (r= 0.160 d^{-1}, λ= 1.173 d^{-1}), whereas the minimum values were recorded on Draga (r= 0.092 d^{-1}, λ= 1.096 d^{-1}). According to the findings of the present study, Draga was considered resistant and a less favorable host plant for the development and reproduction of PTM. These demographic data may be used to better understand the population dynamics of the pest on the six potato cultivars tested, thereby inevitably improve efficient pest management approaches for PTM in both organic and conventional production systems.

Keywords: Host-plant resistance, Life table, Population dynamics, Potato tuber moth.

INTRODUCTION

Potato, with approximately 376 MT annual productions, ranks 6th among the world's major food crops. (Aryal, 2015). Among the many insect pests associated with potato, Potato Tuber Moth (PTM), *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), is one of the most destructive pest in the tropics and subtropics (Raman, 1988). The high reproductive capacity of the pest, in addition to being motivated, and its high adaptability to changes in seasonal and climatic conditions contribute to its significant deleterious effects on potato crops (Vaneva-Gancheva and Dimitrov, 2013). Pest activity does not stop after the crop is harvested, and severe infestation generally continues under typical storage conditions. Damage by PTM ranges from 25 to 100% of potatoes in the field and in storage (Aryal, 2015). Controlling the pest is not easy, and growers widely rely on insecticides and various cultivation practices (Rondon, 2010). Different insecticides (mainly pyrethroids) are used to control the pest on-farm and during storage (Hanafi, 1999), but these insecticides cause health threats to potato producers, their families, consumers, and the environment. The insecticides also induce resistance in PTM and undesirable effects on

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non-target organisms (Aryal, 2015). Since significant economic damage occurs upon infection of tubers, approaches to manage this pest should concentrate on testing host plant resistance. Using crop cultivars that are resilient or less favorable to a pest as sustainable approach is among the main components of biological agriculture (Zehnder *et al*., 2007) and Integrated Pest Management (IPM) programs (Kogan, 1998), which enable ecological and economic management of pests without reliance on pesticides, resulting in reduced negative impacts on natural enemies (Follett, 2017). Furthermore, using host plant resistance along with organic management has become the prevailing approach to organic management of pests (Thomas and Waage, 1996). Therefore, choosing insect-resistant or non-preferred cultivars for potato production is highly important. Integration of host plant resistance to insecticides, proper biological control agents and agronomic practices would offer optimum management choices. Evaluation of PTM reproduction rate on potato cultivars is a good index of crop resistance (Rondon *et al*., 2009; Horgan *et al*., 2010). Efforts to discover resistant potato cultivars have compared damage levels, larval abundance and reproduction values of PTM (Gurr and Symington, 2007; Golizadeh and Razmjou, 2010; Abdallah *et al*., 2012; Alipour and Mehrkhou, 2018).

By using a life table, the suitability and reproduction values of a pest can be properly quantified, since the life table can offer a comprehensive and integrated depiction of the survival, growth, and reproduction of a population (Harcourt, 1969). Nevertheless, in female age-specific life tables (Birch, 1948; Lewis, 1977; Carey, 1993), stage differentiation and the males are neglected, thus resulting in some problems in data analysis. In order to take into account the stage differentiation (i.e., age–stage) of both sexes of PTM, two-sex life table theory, considering both sexes, should be utilized to obtain a realistic assessment of host plant resistance against PTM (Chi and Liu, 1985b; Chi, 1988; Lagnaoui *et al*., 1999; Gurr and Symington, 2007).

In the present research, by applying age–stage, two-sex life table theory, we aimed to assess and compare six common potato cultivars with high yield, good quality and tolerance to dehydration (‘Banba,’ ‘Bellini,’ ‘Draga,’ ‘Marfona,’ ‘Jelly,’ and ‘Milva’) as hosts for PTM toward developing an IPM approach. Another objective we had was to project PTM population growth on the six cultivars using the life table data.

MATERIALS AND METHODS

Rearing the Potato Tuber Moth

The initial population of PTM were originally gathered from potato stores in Sanandaj, Kurdistan Province, Iran, in 2016. The stock cultures were reared on Spirit cultivar of potato at 25±°C, 65±5% RH and 14:10 (L:D) hours photoperiod in a greenhouse. To reduce any intrinsic influence and diet effects, and to keep the potency of the population of the moth, the collected moths from the stock cultures were reared for two generations on each cultivar. In this regard, the potato plants from each of the 6 cultivars, namely, ‘Banba,’ ‘Bellini,’ ‘Marfona,’ ‘Jelly,’ ‘Draga’, and ‘Milva’, were transplanted in pots with about 30 kg of a mix of soil, sand, and peat (1:1:1), and were exposed to PTM.

Life Table Study and Data Analysis

To obtain the cohort eggs of the moth, 50 freshly emerged adults were collected from the mass rearing colony and paired in the oviposition cage consisting of clear plastic containers (20×8×18 cm) with mesh tops that were lined with filter paper. A cohort of eggs consisting of 30 eggs laid on filter paper within 24 h by the paired moth, was gathered. To study the life table of PTM, the gathered eggs were individually placed on the potato leaf disks of the six cultivars in 9

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cm diameter petri dish and potato leaves were used as larval food and checked daily by using a stereomicroscope (Olympus). The developmental time of each PTM from egg to adult emergence was determined on the potato cultivars at 25±1°C, 65±5% RH and 14:10 (L:D) hours photoperiod.

To determine the fecundity of PTM, females were paired with males after adult emergence, and daily fecundity was checked and recorded. The daily number of eggs laid by each female was counted using a stereomicroscope and recorded up to the death of all moths in the cohort. During the entire experimental period, a male was retained with each female. In the case of male death before the female, another male from the mass-colony was added into the oviposition cage; however, the data for the added male were excluded from the life table analysis.

Based on the age–stage, two-sex life table, life history raw data of all individuals were used for analysis (Chi and Liu, 1985a; Chi, 1988). Accordingly, the following life table parameters were determined: age–stage-specific survival rate (s_{xj}) (where x= age in days and j= stage); age–stage-specific fecundity (f_x) (daily number of eggs produced per female of age x); age-specific survival rate (l_x); Adult Preoviposition Period (APOP, the preoviposition period counted from adult emergence); age-specific fecundity (m_x); Total Preoviposition Period (TPOP, the preoviposition period counted from birth); and the population growth the net Reproductive rate (R_0), the finite rate of increase (λ), the intrinsic rate of increase (r), and the mean generation Time (T). According to Chi and Liu (1985b), the age-specific survival rate was calculated as:

$$l_x = \sum_{j=1}^{k} s_{xj} \qquad (1)$$

Where, k is the number of stages. The age-specific (m_x) was determined as:

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

The Oviposition days (O_d) is the number of days females laid eggs, and is determined as:

$$O_d = \frac{\sum_{x=1}^{N_f} D_x}{N_f} \qquad (3)$$

Where, D_x is the number of Days that a female produced offspring and N_f is the Number of female adults.

The net reproduction rate is explained as the mean number of offspring that an individual can produce within its lifetime and it was determined as:

$$R_0 = \sum_{\mathrm{x}=0}^{\infty} l_x M_x \qquad (4)$$

From the Euler-Lotka formula, the intrinsic rate of increase was determined by the iterative bisection with the age indexed from 0 (Goodman, 1982) as:

$$r = 1 = \sum_{\mathrm{x}=0}^{\infty} e^{-r(x+1)} l_x M_x \qquad (5)$$

The finite rate (λ) was determined as:

$$\lambda = e^r \qquad (6)$$

The mean generation time is the length of time that a population requires to increment to R_0-fold of its size as the population reaches the stable age–stage distribution; it was determined as:

$$T = \frac{\ln R_0}{r} \qquad (7)$$

Using the bootstrap method, the standard errors of the developmental times, fecundity, reproduction period and population parameters were determined (Efron and Tibshirani, 1993; Huang and Chi, 2012), with 100,000 bootstraps to reach steady approximations of standard errors, and paired bootstrap test was utilized to compare differences at the 5% significance level (Azadi Dana *et al*., 2018). Computation of the population parameters and performing the bootstrap and paired bootstrap tests were done with TWOSEX-MSChart software ver. 2018 (Chi, 2018). All figures were plotted using Sigmaplot 12.0 software.

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Population Projection

To project the population growth, we used the method of Chi (1990) and the computer program TIMING (Chi, 1990; Chi, 2018). To show the variability of population growth, we sorted the 100,000 bootstrap results of the finite rate (λ) to find the 2.5th and 97.5th percentiles, i.e., the 2,500th and 97,500th sorted bootstrap samples. We then used the bootstrap life table samples that generated the 2.5th and 97.5th percentiles finite rate of increase (λ) to project the population. The results represent the confidence interval of the projected population growth (Huang *et al.*, 2018). We used the method devised by Chi 1990 included in the computer program TIMING-MSChart (Chi, 2018) for hypothetical population projection based on life table parameters.

RESULTS

Developmental Time

PTM completed its development successfully on all the examined potato cultivars (Table 1). Significant differences existed in the egg incubation period among the six cultivars, ranging from 4.35 days on Banba to 3.96 days on Milva (F= 12.692; df= 5, 159; P< 0.05) (Table 1). The development time of the PTM larval stage varied significantly on the tested cultivars and was longer on Banba than on Milva, Jelly, Draga, Bellini and Marfona (F= 45.038; df= 5, 104; P< 0.05). Duration of the pupal stage differed significantly among the cultivars and was longest on Milva (7.80 days) and shortest on Banba (6.86 days) (F= 12.922; df= 5, 90; P< 0.05). The highest (21.93 and 21.50 days) and lowest (19.91 days) pre-adult developmental times (from egg to adult) were recorded on Banba and Milva and Marfona, respectively.

The total developmental longevity time of PTM males (from egg to adult) differed significantly among the cultivars (F= 9.575, df= 5, 45; P< 0.05, being longest on Milva (45.90 days) and shortest on Banba and Jelly (39.00 and 38.40 days). There were no differences in the total developmental time of PTM females on the six tested cultivars (F= 3.591; df= 5, 39; P> 0.05), (Table 1).

Male developmental time varied significantly among the tested potato cultivars, with the longest on Milva (45.90 days) and the shortest on Banba and Jelly (39.00 and 38.40 days) (F= 9.575; df= 5, 45; P< 0.05).

The age-stage survival rate (s_{xj}) indicates the survival probability of a PTM individual to each age x and stage j. Due to variable developmental rates among individuals, considerable overlap was recorded among the pest stages reared on different cultivars (Figure 1). The probability that a newly laid egg survived to the adult stage was 0.233, 0.20, 0.133, 0.166, 0.433, and 0.30 for females and 0. 233, 0.266, 0.233, 0.266, 0.30, and 0.33 for males on Banba, Bellini, Draga, Jelly, Marfona and Milva, respectively.

Reproduction and Life Table Parameters

Considerable variation was observed on the intrinsic rate of increase (*r*), the finite rate of increase (*λ*), and the net Reproductive rate (R_0) of PTM reared on the six potatoes cultivars. The lowest values of intrinsic and finite rate of increases were found on Draga (0.0917 and 1.0960 d^{-1}, respectively), while the maximum values of either intrinsic rate of increase or the finite rate of increase values were found on Marfona (0.1600 and 1.1730 d^{-1}, respectively) (Table 2).

The mean generation Time (T) of PTM was not significantly different among the six potato cultivars (F= 12.153; df= 5, 174; P< 0.05). However, there was a significant difference in total Fecundity (F) between the tested cultivars (F= 8.466, df= 5, 39; P< 0.05) . The maximum fecundity was found on Marfona (103.08 eggs/female) and the

Table 1. Mean (±SE) duration of different developmental stages (day) of *Phthorimaea operculella* reared on six potato cultivars.[a]

Stage	Potato cultivars								
	Banba	Bellini	Draga	Jelly	Marfona	Milva			
	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	df	*F*	*P*
Egg	4.35 ± 0.12a	4.04 ± 0.04ab	4.00 ± 0.07ab	4.11 ± 0.06ab	4.14 ± 0.08ab	3.96 ± 0.06b	5, 159	12.692	< 0.05
Larva	11.00 ± 0.46a	9.19 ± 0.25bc	9.29 ± 0.29abc	9.47 ± 0.44b	8.43 ± 0.29c	9.77 ± 0.46ab	5, 104	45.038	< 0.05
Pupa	6.86 ± 0.18b	7.00 ± 0.28ab	7.73 ± 0.27ab	7.33 ± 0.27ab	7.36±0.19ab	7.80 ± 0.30a	5, 90	12.922	< 0.05
Preadult	21.93 ± 0.50a	20.21 ± 0.43ab	20.73 ± 0.38ab	20.60 ± 0.65ab	19.91 ± 0.27b	21.50 ± 0.57a	5, 91	7.49	< 0.05
Female longevity (Adult)	16.57 ± 1.74ab	13.17 ± 0.98b	20.75 ± 7.88ab	15.60 ± 2.66ab	18.38 ± 2.06a	14.60 ± 2.47ab	5, 39	4.87	< 0.05
Male longevity (Adult)	16.14 ± 1.40c	22.25 ± 1.15ab	23.29 ± 2.75abc	17.40 ± 2.34bc	22.33 ± 2.12ab	24.00 ± 1.40a	5, 45	18.55	< 0.05
Female total developmental time	37.57 ± 2.16a	33.00 ± 1.37a	40.50 ± 7.71a	35.40 ± 2.68a	38.46 ± 2.25a	35.70 ± 2.38a	5, 39	3.59	> 0.05
Male total developmental longevity time	39.00 ± 1.56b	42.75 ± 1.32ab	44.57 ± 2.55ab	38.40 ± 2.26b	42.00 ± 2.18ab	45.90 ± 1.74a	5, 45	9.57	< 0.05

[a] Standard errors were estimated by using the bootstrap technique with 100000 resamplings. The difference was compared with paired bootstrap test. The means within a row followed by different letters indicate significant differences among the six cultivars.

Table 2. Reproduction and life table parameters (Mean±SE) of *Phthorimaea operculella* reared on six potato cultivars.[a]

Parametres[b]	Potao cultivars								
	Banba	Bellini	Draga	Jelly	Marfona	Milva	df	*F*	*P*
R_0 (Offspring/Individual)	17.80 ± 6.40b	10.20 ± 5.38b	9.80 ± 5.05b	14.86 ± 7.17b	44.66 ± 10.84a	28.90 ± 9.51ab	5, 174	92.241	< 0.05
r (d^{-1})	0.1173 ± 0.020b	0.1019 ± 0.031ab	0.0917 ± 0.025b	0.1139 ± 0.029ab	0.1600 ± 0.0118a	0.1386 ± 0.015ab	5, 174	42.369	< 0.05
λ (d^{-1})	1.124 ± 0.020ab	1.1073 ± 0.033ab	1.096 ± 0.027b	1.120 ± 0.031ab	1.173 ± 0.013a	1.148 ± 0.017ab	5, 174	45.029	< 0.05
T (Day)	24.52 ± 0.70a	22.77 ± 0.64a	24.87 ± 1.92a	23.67 ± 1.41a	23.73 ± 0.47a	24.26 ± 0.44a	5, 174	12.153	< 0.05
F (Egg/Female)	76.29 ± 11.75ab	51.00 ± 21.37b	73.50 ± 20.80ab	89.20 ± 25.87ab	103.08 ± 13.12a	86.70 ± 18.80ab	5, 39	8.466	< 0.05
O_d (Day)	5.43 ± 0.50bc	4.17 ± 0.65cb	7.75 ± 2.66abc	8.20 ± 1.07a	6.69 ± 0.67ab	6.70 ± 1.00 ab	5, 39	11.327	< 0.05
APOP (Day)	1.57 ± 0.60a	1.50 ± 0.43a	1.50 ± 1.19a	1.20 ± 0.97a	0.77 ± 0.30a	0.60 ± 0.22a	5, 39	4.136	> 0.05
TPOP (Day)	22.57 ± 0.80a	21.33 ± 0.84a	21.25 ± 1.30a	21.00 ±1.05a	20.85 ± 0.41a	21.70 ± 0.84a	5, 39	4.940	< 0.05

[a] Standard errors were estimated by using the bootstrap technique with 100000 resamplings. The difference was compared with paired bootstrap test ($P < 0.05$). The means within a row followed by different letters indicate significant differences between six cultivars. [b] R_0: Net Reproductive rate; r: Intrinsic rate of increase; λ: Finite rate of increase; T: Mean generation Time; F: Fecundity; O_d: Oviposition days (d); APOP: Adult Preoviposition Period, TPOP: Total Preoviposition Period (from egg to first oviposition).

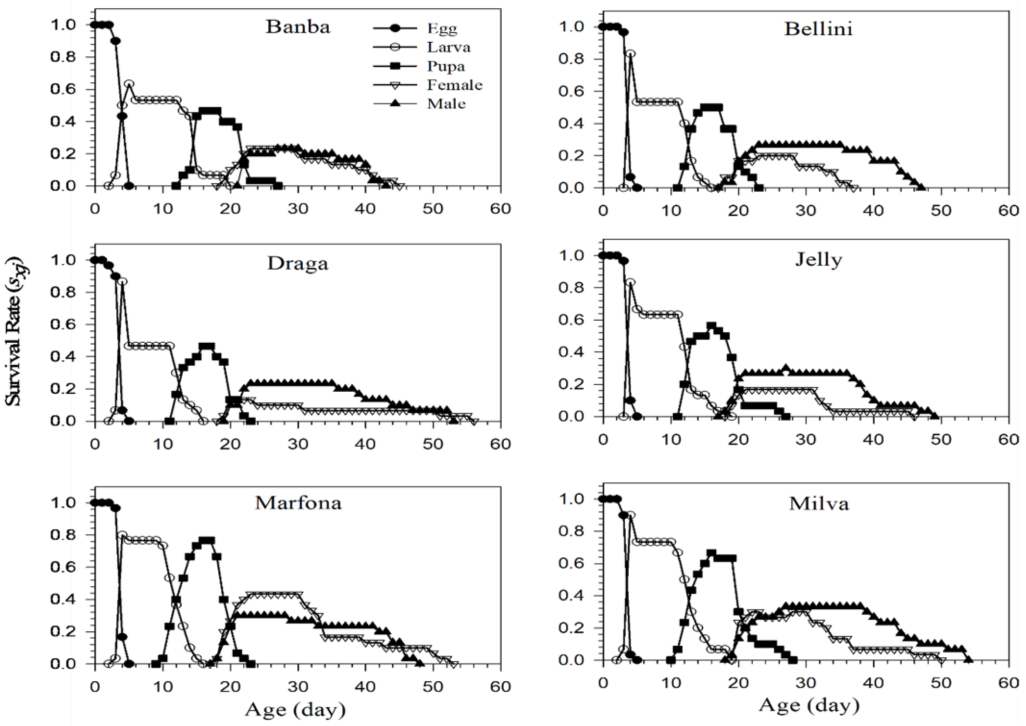

Figure 1. Age-stage survival rate (s_{xj}) of *Phthorimaea operculella* reared on six potato cultivars.

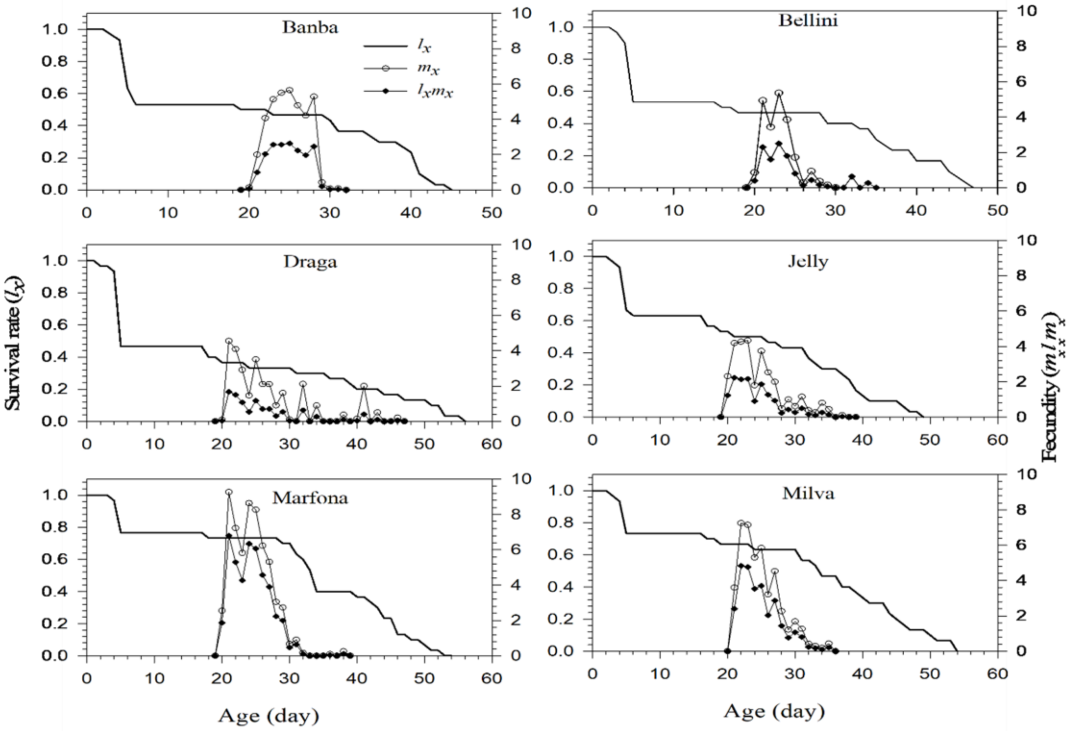

Figure 2. Age-specific survival rate (l_x), age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) of *Phthorimaea operculella* reared on six potato cultivars.

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minimum fecundity was observed on Bellini (51.00 eggs/female), but the latter was not statistically different from Draga, Jelly, Milva or Banba (F= 12.153; df= 5, 39; P< 0.05).

Oviposition days (O_d) by PTM females was longest on cultivar Jelly (8.20 days), which was significantly different from Bellini (4.17 days) and Banba (5.43 days) (F= 11.327; df= 5, 39; P< 0.05).

Neither the adult preoviposition period (APOP) nor the total pre-oviposition (TPOP) of PTM females was significantly different among the potato cultivars (F= 4.940; df= 5, 39; P< 0.05) (Table 2).

Figure 2 shows the age-specific survival rate (l_x), (m_x), and net maternity ($l_x m_x$) of PTM. The highest age-specific fecundity (m_x= 9.27 eggs) was found on Marfona at age 24 days (Figure 2).

The plot of the age-stage life expectancy (e_{xj}) for PTM on the six potato cultivars is represented in Figure 3. It provides the time that individuals of age *x* and stage *j* are expected to live after age *x*. Since no mortality factors other than aging exist under laboratory conditions, the e_x-curves decreased with age in general. The highest life expectancy of a newly laid PTM eggs was 31 days on Marfona while this value was lowest on cv. Banba and Bellini (21 days). Figure 4 presents the plot of the age–stage reproductive value (v_{xj}) of PTM on the six potato cultivars. The age-stage reproductive value (v_{xj})—indicating the contribution of an individual at age *x* and stage *j* to the future population—increased significantly when adults emerged and the peak of v_{xj} of the pest appeared at age 20 days on all cvs (Figure 4)

The population growth and variability results are shown in Figure 5. The fastest growth was observed on Marfona. The population size at day 30 that was projected

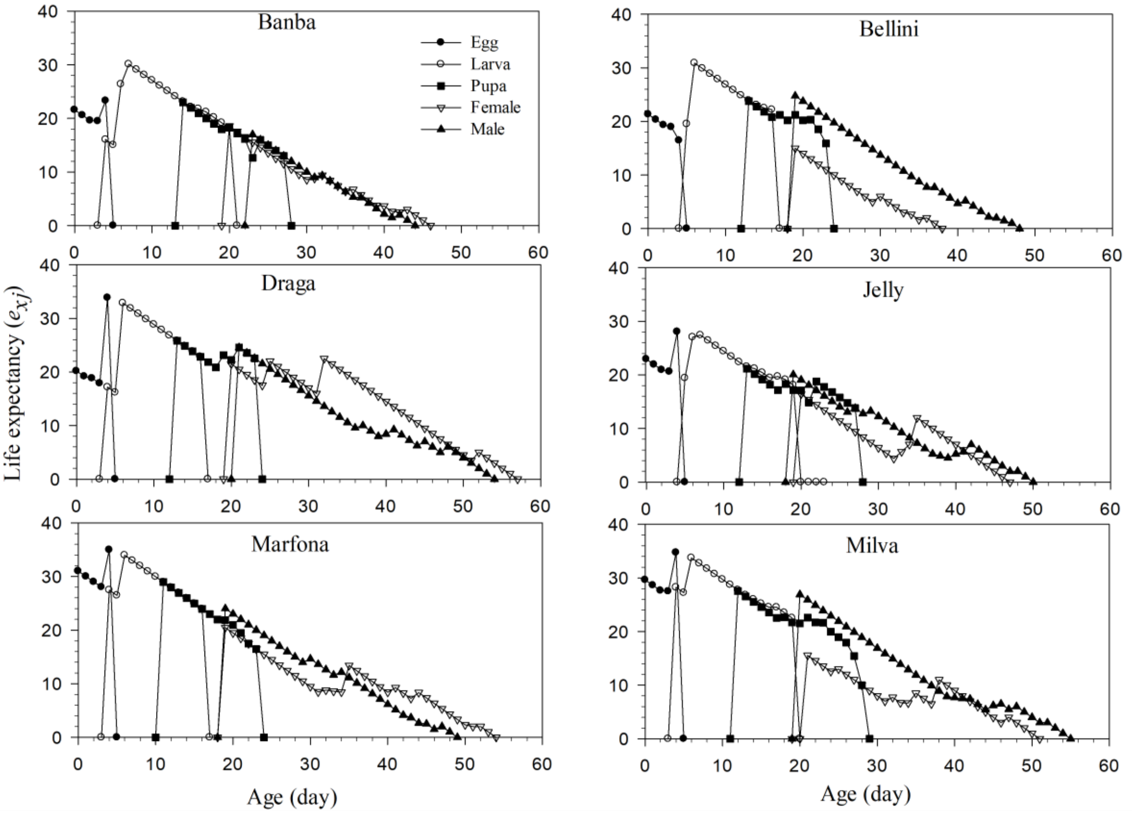

Figure 3. Age-stage-specific life expectancy (e_{xj}) of *Phthorimaea operculella* reared on six potato cultivars.

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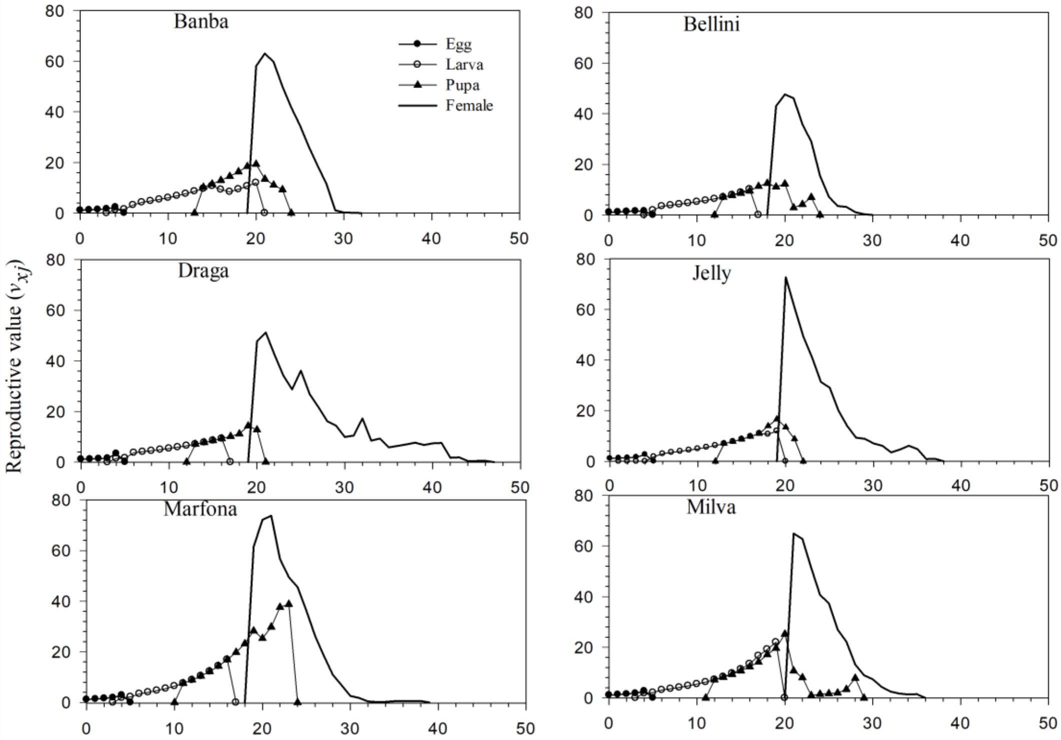

Figure 4. Age-stage-specific reproductive value (v_{xj}) of *Phthorimaea operculella* reared on six potato cultivars.

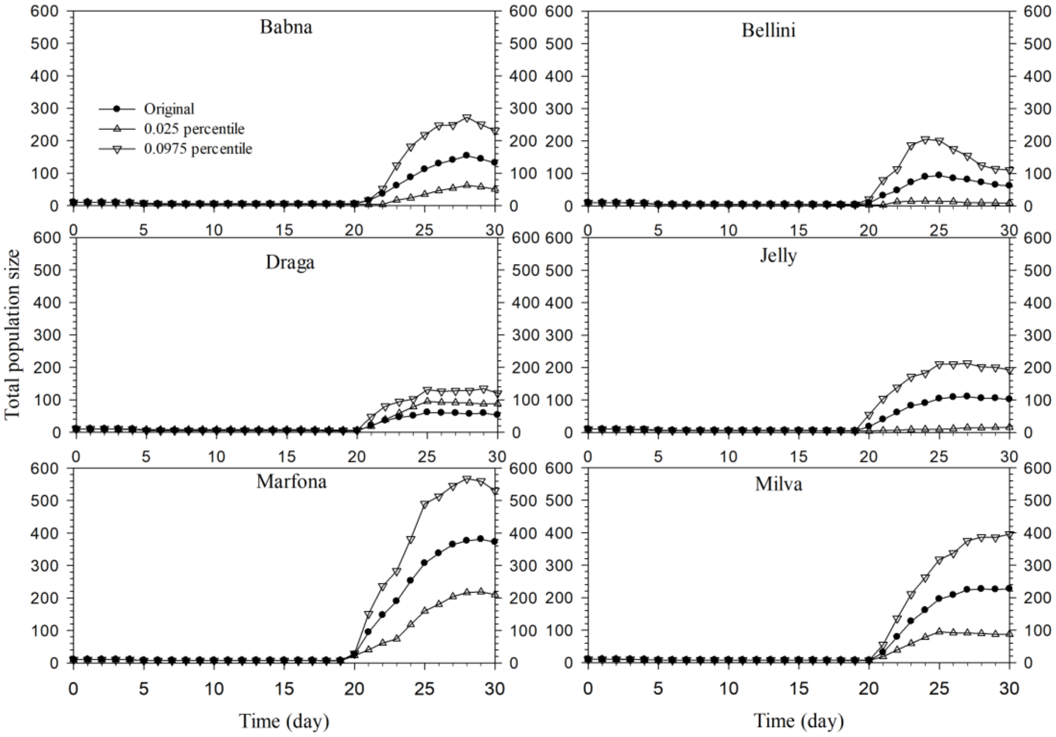

Figure 5. Population projection of *Phthorimaea operculella* reared on six potato cultivars based on the 2.5th and 97.5th percentiles of the confidence interval of the finite rate of increase (λ).

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by using life tables of 0.025 and 0.975 percentiles gave the range 20~567.

DISCUSSION

There are various strategies for combatting PTM damage, including logical use of pesticides (Saour, 2008), modification of cultivation practices (Hanafi, 1999), biological control (Saour, 2004), and use of resistant plant varieties (Sileshi and Teriessa, 2001; Horgan *et al*., 2010). Indeed, using host plants that are resistant to insect pests and elucidating the effects of these plants on the ecology of pests are vital for making management decisions (Greenberg *et al*., 2002). Moreover, insect-resistant plants not only adversely influence the biological features of the pest so as to provide sustainable control in the field and storage, they also indirectly improve the efficacy of external factors such as the natural enemies of the pest which are indiscriminately targeted by chemical pesticides (Karami *et al*., 2018 a and b).

The egg incubation period of PTM ranged from 3.96 to 4.35 days on the various potato cultivars, which is similar to the incubation period of 4.5 days reported by Rondon (2010) and Salavati *et al.* (2017). However, other studies conducted on various potato cultivars have reported shorter incubation times (González-Domínguez *et al*., 2017; Karlec *et al*., 2017). Also, Alipour and Mehrkhou (2018) reported an incubation period (7.00 eggs) that noticeably was greater than the similar studies.

In the present research, PTM had a pre-adult development period of 21 days, shorter than those previously reported in other studies (Langford and Cory, 1932; Santorini, 1971; Chauhan and Verma, 1991; Alipour and Mehrkhou, 2018). This increase in developmental rate may be attributable to differences in the nutritive quality of the host plants from which the pests feed. Thus, while rearing PTM on leaves and tubers, significant variations occurred in the pre-adult developmental times (Golizadeh *et al*., 2014).

Differences in the nutritional quality of the leaves of the six varieties may be related to different concentrations of nutritive and secondary metabolites (Stoner, 1996; Lachman *et al*., 2001) or to differences in the physical characteristics of the leaves (Musmeci *et al*., 1997). Among the tested cultivars, the number of eggs produced by each female varied considerably. The maximum of the total fecundity in the present study was 103.08 eggs, on cultivar Marfona, which is lower than that reported by Golizadeh and Razmjou (2010) on numerous potato cultivars, including Marfona; Golizadeh and Razmjou (2010) reported a lifetime fecundity of 113.27 eggs for PTM on Marfona. Part of this variation may be explained by the different host materials supplied to the insect; Golizadeh and Razmjou (2010) used tubers as food sources, whereas we used leaves in the present study.

The number of eggs laid by each female PTM reared on different potato cultivars by Alipour and Mehrkhou (2018) was 246 eggs. This difference could be related to food sources consumed during the larval stage.

The total and adult pre-oviposition periods of PTM reared on the six potato cultivars were variable. The values measured for APOP and TPOP indicated no relationship between the duration of the periods and the various potato leaves. However, it is known that less food for a larva lowers its weight, which adversely affects the fecundity of the resulting adult (Musmeci *et al*., 1997). Our findings are higher than those of Golizadeh and Razmjou (2010) who reported 0.27±0.14 days for Marfona.

In the present research, the duration of oviposition ranged from 4.17 to 8.20 days on the different cultivars, with the longest on Jelly, this period on tubers was reported by by Salavati *et al.* (2017) from 10.47 to 10.00 days, which was shorter than the present research. Golizadeh and Razmjou (2010) calculated an egg-laying period of 4.18 days,

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which is less than our estimate of 6.69 days in Marfona.

Plant species differ widely in their appropriateness as hosts for specific insects in terms of insect survival, development, and reproductive rates (Lenteren and Noldus, 1990). Since the generally used term ‘oviposition period’ is defined as the period from the prime to the ultimate age of oviposition, it does not provide the actual number of days during which the female laid eggs. Hence, we used ‘oviposition days’ in this study to define the true number of days during which the female laid eggs. The impacts of the cultivars can be related to the ‘adjustment expense’ of the herbivores in accepting a new plant. However, this adjustment effect is more pronounced in the ovipositing females than their male counterparts. Some research do not discuss the costs of herbivores adaptation when assessing the plant resistance. This is especially true when vegetarians are kept in cultivars or species different than the ones used in the experiments (Underwood and Rausher, 2000; Rovenská *et al*., 2005). Plant species differ significantly in their suitability as hosts for mite pests in terms of survival, development, and reproduction. The development and reproduction of insects and mites vary considerably depending on the quality and quantity of the food consumed (Lenteren and Noldus, 1990; Murungi *et al*., 2010; Bayu *et al*., 2017). The nutritional value of a host plant in turn affects the growth rate of both insects and spider mites, with higher nutritional quality resulting in shorter developmental times and greater reproductive potential (Musmeci *et al*., 1997; Adango *et al*., 2006). Additionally, lengthening the duration of the pre-adult time leads to longer exposure to natural enemies (Price *et al*., 1980). The survival curves of PTM we observed on the various potato cultivars were almost identical and, likely, reflected physiological declines associated with aging (Gabre *et al*., 2005). The reproduction value in the pre-reproduction period along with aging increases the probability of transformation of the pre-adult female insect into an adult female; however, the rise or fall of the reproduction value depends on the reproduction increase or decrease. Along with aging, the value of reproduction in the pre-adult stage increases, and these parameters reach their apex when the female insects appear, the maximum of which occurs early in adulthood and gradually declines to zero (Tsai and Chi, 2007).

Our findings support the investigation of reproduction and life table parameters to assess the resistance of potato cultivars to PTM. The estimated intrinsic rate of increase (*r*) of PTM ranged from 0.092 d^{-1} (Draga) to 0.160 d^{-1} (Marfona). In a similar study aimed at evaluating the resistance of potato cultivars to PTM, differences in the intrinsic rate of natural increase were also reported (Golizadeh *et al*., 2014; Salavati *et al*., 2017). A similar close tendency was observed in *P. operculella* on different potato cultivars tubers (Alipour and Mehrkhou, 2018). The rate of natural increase is a key indicator of the proficiency of a pest to thrive on a host plant, because it includes numerous life-history elements such as survival, development and fecundity (Birch, 1948). Several factors influence the intrinsic rate of the natural increase, including survival, development rate, and particularly generation time, which sufficiently sums up the physical characters of an insect in terms of its capability to proliferate. Thus, it can be an important indicator of an arthropod’s potential to develop into an infestation and a host plant’s potential to become resistant (Ullah *et al*., 2014; Ullah and Lim, 2015). Slight differences in life-history parameters could influence the projected population growth results estimated in this study. The greater susceptibility of a host plant to attack by a phytophagous pest is indicated by higher values of the intrinsic rate of increase (Sedaratian *et al*., 2011).

The net reproductive rate, which is described as the average number of female offspring produced per female during her lifetime, varied between 9.80 and 44.67 d^{-1}

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in our study, in a similar study by Salavati et *al*. (2017). Also, Alipour and Mehrkhou (2018) reported a net reproductive rate for *P. operculella* (53.22 offspring on Impala) that noticeably was greater than the present study. The mean generation time in our study did not vary on the six potato cultivars.

All six of the tested cultivars sustained damage from PTM. Nevertheless, the observed differences in the demographic parameters indicate the pest's high preference for Marfona in comparison to the other cultivars. Before a definitive conclusion can be drawn in terms of host suitability and pest management, the data should be considered as preliminary. However, other factors may be included in resistance mechanisms to pests. These elements can be summed up as structural features of cultivars, principally: the form of trichomes (Luczynski *et al*., 1990); the nutritional value of the plant (Rodriguez *et al*., 1970); variability of volatile organic defence compounds of cultivars and flower, fruit and foliage elimination (Hamilton-Kemp *et al*., 1989); water and salt marsh tolerance (Wermelinger *et al*., 1991); lesion-enforcing agents (Steinite and Ievinsh, 2002); the season (Dabrowski *et al*., 1971); day length (Patterson *et al*., 1994); irrigation handling (Opit *et al*., 2001); and growing systems (Martins *et al*., 2017). However, among the most important factors affecting a pest's host acceptability and reproduction are the existence of nutrients and secondary metabolites in the host plant; the occurrence of repulsive or adsorbent unstable composites; and the existence and concentration of glandular and/or non-glandular cilium on stalk surfaces and leaves (Boom *et al*., 2003; Hoy, 2011).

Shedding light on the impact of various host types on the bionomics of insects is of tremendous importance to pest management (Greenberg *et al*., 2002). The host plant's vulnerability to insects and mites changes depending on the host plant species or cultivar (Alford, 1972). However, none of the current commercially developed potato cultivars is resistant to PTM attack. In this work, some potato cultivars might be less appropriate as a PTM host than the other ones. A slower increase in the pest population was indicated by the projected growth, providing more cases for operative management approaches.

CONCLUSIONS

In conclusion, Draga was less favorable for the development and reproduction of PTM. Hence, the effectiveness of control actions against arthropod pests as one of the major components of an IPM strategy can be improved by using resistant and partially resistant cultivars such as Draga. Our findings also affirm that age–stage, two-sex life table theory is a valuable instrument to assess host plant resistance to an insect pest.

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مقایسه دموگرافی بید سیب زمینی *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) روی ارقام مختلف سیب زمینی

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چکیده

بید سیب زمینی *Phthorimaea operculella* (Zeller) یکی از مهم ترین آفات سیب زمینی در مزرعه و انبار است. استفاده از ارقام مقاوم بعنوان یکی از روش های سازگار با محیط زیست می تواند در کنترل آفت مفید واقع شود. بنابراین هدف از این تحقیق ارزیابی میزان مقاومت شش رقم رایج سیب زمینی (بامبا، بلینی، دراگا، جیلی و میلوا) نسبت به آفت مذکور در شرایط آزمایشگاهی (دماي ۲±۲۵ درجه سلسیوس، رطوبت نسبي ۵±۶۵ درصد و دوره نوري ۱۴ ساعت روشنايي و ۱۰ ساعت تاريكي) بود. در این تحقیق، فراسنجه های زیستی بید سیب زمینی روی رقم های مختلف سیب زمینی بر اساس تئوری جدول زندگي دو جنسي سن- مرحله بعنوان شاخص مناسب ارزیابی حساسیت و مقاومت، مورد بررسی و مطالعه قرار گرفت. نتایج نشان داد که مدت زمان دوره رشد و نمو دوره قبل از بلوغ حشره مورد نظر در رقم مارفونا (۱۹.۹۱ روز) کوتاه‌تر و در رقم مارفونا (۲۱/۹۳ روز) طولانی‌تر از دیگر ارقام مورد بررسی بود، همچنین طولانی‌ترین و کوتاه‌ترین طول دوره تخم‌ریزی بترتیب روی رقم جیلی (۸/۲۰ روز) و بلینی (۵/۴۳ روز) بدست آمد. همچنین بررسي فراسنجه‌های رشد جمعیت نشان داد که بیشترین نرخ ذاتی افزایش جمعیت (r) و نرخ متناهی افزایش جمعیت (λ) روی رقم مارفونا (λ =۱/۱۷۳ ، r =۰/۱۶۰ در روز) و کمترین فراسنجه‌های مورد نظر روی رقم دراگا(λ =۱/۰۹۶ ، r =۰/۰۹۲ در روز) بدست آمد. با توجه به نتایج تحقیق حاضر، رقم دراگا رقم مقاوم و میزبانی با مطلوبیت کمتر برای رشد و نمو و تولیدمثل آفت بید سیب زمینی است. فراسنجه های دموگرافی بدست آمده را می‌توان جهت درک بهتر پویایی جمعیت آفت مورد نظر روی شش رقم مورد آزمایش مورد استفاده قرار داد و در مدیریت کارامد این آفت در سیستم های ارگانیک و رایج کشت سیب زمینی مورد از آنعها بهره جست.

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