Development and Age-Specific Mortality of Diamondback Moth on *Brassica* Host Plants: Pattern and Causes of Mortality Under Laboratory Conditions

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ABSTRACT The development and mortality of diamondback moth, *Plutella xylostella* (L.), were studied in laboratory at 25 ± 1°C, 65 ± 5% RH, and a photoperiod of 16:8 (L:D) h on 10 canola cultivars: 'SLM$_{046}$,' 'Opera,' 'Okapi,' 'RGS$_{003}$,' 'Modena,' 'Sarigol,' 'Zarfam,' 'Licord,' 'Hayula$_{420}$,' and 'Talaye.' Larvae successfully survived on all host plants. The developmental time of immature stages ranged from 15.03 ± 0.15 d on Hayula$_{420}$ to 16.65 ± 0.29 d on Opera, with a larval period ranging from 7.67 to 8.91 d on these cultivars. Adult female longevity was longest on Hayula$_{420}$ without any supplemental food. Life table entropy values ($H < 0.5$) indicated Deevey's type I survivorship curve; however, the value of 0.541 on Hayula$_{420}$ ($H > 0.5$) corresponded to type III. Major mortality parameters such as fraction of original cohort dying between successive days of age, death frequency (d_x) of immature *P. xylostella*, average daily mortality ($\bar{\mu}_x$), and central death rate (m_x) were evaluated on canola cultivars and indicated that the highest m_x occurred on RGS$_{003}$, with relatively low potential of population growth, on fifth day of life when the pest is in early larval stages (L1 and L2). The early instars are the most susceptible stages and suffer the highest cause-specific mortality under laboratory conditions.

KEY WORDS age-specific mortality, *Plutella xylostella*, death frequency

The diamondback moth, *Plutella xylostella* (L.), is a serious pest of cruciferous crops worldwide (Talekar and Shelton 1993), and annual costs for its management are estimated at US$1 billion (Javier 1992, Talekar 1992, Talekar and Shelton 1993), in addition to the resulting crop losses (Sarfraz et al. 2006). The quality of host plant can affect many biological and physiological aspects of herbivorous arthropods through physiological modifications, including reductions in life span, developmental rate, fertility, fecundity, and changes in sex ratio (Yin et al. 2008).

How and why insect numbers change through time and space has been a central subject in ecological research and life tables have been used to understand temporal and spatial patterns in insect numbers (Zalucki et al. 2002, Peterson et al. 2009). Demographic approaches focusing on age-specific mortality rates are becoming increasingly common throughout the fields of life-history evolution, ecology, and biogerontology, so well defined statistical techniques for quantifying patterns of mortality within a cohort and identifying variations in age-specific mortality among cohorts are necessary (Pletcher 1999). Age-specific mortality rates can be compared directly between ages or between populations; moreover, age-specific mortality is a useful parameter in insect actuarial studies due to its simpleness, easy measurability, easy modeling, and applicability to all species (Carey 2001).

Frequency distribution of deaths (d_x), central death rate (m_x), average daily mortality ($\bar{\mu}_x$), and life table entropy (H) are major mortality parameters (Carey 2001), each can be used as a communicative scheme of mortality in insect herbivores. Here, the first three parameters were used to describe mortality during immature developmental time of *P. xylostella*, whereas the fourth was explored in whole life span descriptions of mortality. Although the first three parameters focus on mortality over time, the entropy parameter provides a useful summary measure for characterizing differences in shapes of survival curves among cohorts (Carey 2001).

Mortality in early larval stages of lepidopteran insects is usually ≈25–75%, which is high and noticeable (Zalucki et al. 2002) and can be an important theme in population biology of this order of insects. In this study, we describe the cause-specific probabilities of death in *P. xylostella* immature stages and identify the

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Table 1. Mortality parameter notations, formulae, and descriptions used in this study

Parameter type and description	Notation and formula[a]
Central death rate: Number dying at age x relative to no. at risk	$m_x = \frac{q_x}{1 - 1/2q_x}$
Avrg daily mortality: daily mortality given expectation of life, e_0	$\bar{\mu} = \frac{1}{e_x}$
Entropy: days gained per averted death	$H = \sum_{x=0}^{\omega} e_x d_x$
Death distribution: fraction of original cohort dying between x and x + 1	$d_x = l_x - l_{x+1}$

[a] For details on mortality parameters, see Carey (2001).

patterns (e.g., survival curve type) and discuss the cause of mortality (e.g., failure to establish, which is a host-related factor) under laboratory conditions. The overall goal of our research is to better understand *P. xylostella* biology and its intrinsic susceptibilities through its life span that cause natural but accidental death as an age-independent early mortality, to develop more precise management strategies of *P. xylostella* in canola.

Materials and Methods

Experimental Conditions. The original population of *P. xylostella* was collected from the *Brassica* fields of Horticultural Research Center of University of Tehran in Karaj, Iran, during May 2009. Canola *Brassica napus* L. 'SLM$_{046}$,' 'Opera,' 'Okapi,' 'RGS$_{003}$,' 'Modena,' 'Sarigol,' 'Zarfam,' 'Licord,' 'Hayula$_{420}$,' and 'Talaye' were obtained from the Seed and Plant Improvement Institute in Karaj, Iran. The seeds were planted in sandy loam soil in 20-cm-diameter plastic pots in greenhouse without any fertilizer. These cultivars were grown at 27 ± 5°C under natural light conditions. Excised leaves of canola cultivars were used for experiments when plants were 4 wk old. The stock culture of *P. xylostella* was maintained in a growth chamber at 25 ± 1°C, 65 ± 5% RH, and a photoperiod of 16:8 (L:D) h. The population of *P. xylostella* was reared on each cultivar for more than two generations before experiments started.

Developmental Time and Longevity. Developmental time of *P. xylostella* was determined on each cultivar. *P. xylostella* eggs were removed from a surface of the host plant leaf using a fine brush and placed on a leaf disk in individual petri dishes (8.0 cm in diameter) (50–70 eggs on different host plants). The petri dishes were placed in a growth chamber, 25 ± 1°C, 65 ± 5% RH, and a photoperiod of 16:8 (L:D) h. The eggs were checked daily, and the number of larvae emerging was recorded daily. This regular checking of eggs either was continued until all eggs either hatched or could be classified as dead (eggs collapsed and shrivelled). Development of larvae and pupae was observed in the growth chamber at similar conditions provided for eggs. To evaluate the development on host plants, second instars from the previous experiments were placed individually on the leaf disks of host plants in 8.0-cm-diameter petri dishes (neonates enter leaf parenchyma after hatching). Each host plant treatment

Table 2. Mean ± SE duration of immature stages of *P. xylostella* on 10 canola cultivars under laboratory conditions

Canola cultivar	Incubation period (d)	Larval period (d)					Prepupal period (d)	Pupal period (d)	Developmental time (d)
		Instar 1	Instar 2	Instar 3	Instar 4	Total larvae			
SLM$_{046}$	3.4 ± 0.07a (n = 52)	2.3 ± 0.08a (n = 45)	1.9 ± 0.11d (n = 43)	2.3 ± 0.11b (n = 42)	1.4 ± 0.08bcd (n = 42)	8 ± 0.14cd (n = 42)	0.2 ± 0.06ab (n = 42)	4.2 ± 0.08abc (n = 36)	15.7 ± 0.14cd (n = 36)
Okapi	3.0 ± 0.02c (n = 61)	1.7 ± 0.06c (n = 56)	2.2 ± 0.08bcd (n = 53)	2.7 ± 0.09ab (n = 53)	1.2 ± 0.06cde (n = 53)	7.8 ± 0.09d (n = 53)	0.2 ± 0.06a (n = 53)	4.0 ± 0.08c (n = 53)	15.1 ± 0.13e (n = 52)
Modena	3.0 ± 0.02c (n = 60)	1.9 ± 0.02b (n = 55)	2.1 ± 0.09bcd (n = 51)	2.6 ± 0.10ab (n = 49)	1.2 ± 0.06de (n = 49)	7.8 ± 0.13d (n = 49)	0.3 ± 0.06a (n = 49)	4.1 ± 0.10bc (n = 48)	15.3 ± 0.16de (n = 48)
RGS$_{003}$	3.1 ± 0.03c (n = 64)	2.0 ± 0.03b (n = 49)	2.5 ± 0.10ab (n = 47)	2.5 ± 0.13ab (n = 46)	1.6 ± 0.09ab (n = 46)	8.6 ± 0.13ab (n = 46)	0.1 ± 0.05ab (n = 46)	4.4 ± 0.08ab (n = 46)	16.2 ± 0.13ab (n = 46)
Talaye	3.1 ± 0.03c (n = 57)	2.0 ± 0.04b (n = 52)	2.6 ± 0.17a (n = 49)	2.6 ± 0.12ab (n = 47)	1.5 ± 0.08bc (n = 46)	8.6 ± 0.18ab (n = 46)	0.1 ± 0.05ab (n = 46)	4.3 ± 0.08ab (n = 46)	16.1 ± 0.18bc (n = 45)
Zarfam	3.1 ± 0.04c (n = 59)	2.3 ± 0.08a (n = 54)	2.2 ± 0.11bcd (n = 52)	2.6 ± 0.13ab (n = 51)	1.7 ± 0.09a (n = 50)	8.7 ± 0.18ab (n = 50)	0.02 ± 0.02b (n = 49)	4.5 ± 0.09a (n = 46)	16.2 ± 0.12ab (n = 45)
Opera	3.5 ± 0.07a (n = 63)	2.3 ± 0.07a (n = 45)	2.7 ± 0.18a (n = 37)	2.5 ± 0.15ab (n = 35)	1.3 ± 0.09cde (n = 35)	8.9 ± 0.23a (n = 34)	0.2 ± 0.07a (n = 34)	4.3 ± 0.12ab (n = 30)	16.6 ± 0.29a (n = 29)
Sarigol	3.0 ± 0.05c (n = 62)	1.9 ± 0.06b (n = 53)	2.4 ± 0.11abc (n = 49)	2.8 ± 0.08a (n = 49)	1.3 ± 0.05cde (n = 49)	8.4 ± 0.13bc (n = 49)	0.1 ± 0.05ab (n = 46)	4.1 ± 0.07bc (n = 46)	15.7 ± 0.13cd (n = 45)
Licord	3.2 ± 0.06b (n = 60)	1.9 ± 0.07b (n = 48)	2.4 ± 0.11ab (n = 44)	2.7 ± 0.11ab (n = 43)	1.3 ± 0.07cde (n = 43)	8.4 ± 0.12bc (n = 43)	0.1 ± 0.05ab (n = 43)	4.4 ± 0.09ab (n = 38)	16.1 ± 0.17bc (n = 38)
Hayula$_{420}$	3.1 ± 0.03c (n = 59)	1.9 ± 0.06b (n = 43)	2.0 ± 0.12cd (n = 38)	2.6 ± 0.10ab (n = 37)	1.1 ± 0.06e (n = 37)	7.7 ± 0.16d (n = 37)	0.1 ± 0.06ab (n = 36)	4.2 ± 0.09bc (n = 35)	15.0 ± 0.15e (n = 35)

Values in each column followed by the same letter are not significantly different at the $P = 0.05$ level (Duncan's multiple range test after one-way ANOVA).

Table 3. Mean ± SE adult longevity and whole life span of *P. xylostella* on 10 canola cultivars under laboratory conditions

Canola cultivar	Adult longevity (d)		Whole life span (d)	
	Male	Female	Male	Female
SLM_{046}	5.4 ± 0.33c (n = 15)	5.2 ± 0.26c (n = 18)	21.3 ± 0.38cd (n = 15)	20.7 ± 0.26cde (n = 18)
Okapi	5.5 ± 0.27c (n = 17)	5.1 ± 0.34c (n = 20)	20.3 ± 0.30d (n = 17)	19.5 ± 0.31e (n = 20)
Modena	5.9 ± 0.47bc (n = 18)	5.5 ± 0.47bc (n = 20)	21.2 ± 0.57cd (n = 18)	20.4 ± 0.53de (n = 20)
RGS_{003}	5.1 ± 0.37c (n = 23)	6.1 ± 0.44bc (n = 19)	21.4 ± 0.45cd (n = 23)	22.1 ± 0.54bc (n = 19)
Talaye	5.9 ± 0.39bc (n = 19)	6.0 ± 0.24bc (n = 19)	22.1 ± 0.45bc (n = 19)	21.7 ± 0.32bcd (n = 19)
Zarfam	7.0 ± 0.53b (n = 18)	6.7 ± 0.49b (n = 20)	23.7 ± 0.52b (n = 18)	22.4 ± 0.47b (n = 20)
Opera	5.4 ± 0.38c (n = 9)	6.1 ± 0.43bc (n = 16)	22.2 ± 0.32bc (n = 9)	22.3 ± 0.59b (n = 16)
Sarigol	6.6 ± 0.47bc (n = 18)	6.2 ± 0.43bc (n = 17)	22.4 ± 0.59bc (n = 18)	21.6 ± 0.50bcd (n = 17)
Licord	5.6 ± 0.42bc (n = 13)	5.4 ± 0.32c (n = 20)	22.1 ± 0.50bc (n = 13)	21.0 ± 0.38bcd (n = 20)
$Hayula_{420}$	11.1 ± 0.70a (n = 15)	10.1 ± 0.60a (n = 17)	26.1 ± 0.72a (n = 15)	25.1 ± 0.68a (n = 17)

Values in each column followed by the same letter are not significantly different at the $P = 0.05$ level (Duncan's multiple range test after one-way ANOVA).

was replicated 50–70 times. All larvae were checked daily for their developmental stage. Survival rate and developmental time were recorded for all preimaginal stages and the sex of emerged adults was determined.

Mortality. Four mortality parameters including central death rate, life table entropy, average daily mortality, and death distribution (Table 1) were used to evaluate the pattern of mortality with age. Central death rate, also known as the age-specific death rate (m_x), is defined as the number of deaths in a specified period in a specific age category divided by the population at risk. It is essentially a weighted average of the force of mortality between ages x and x + 1. Life table entropy (H) is a measure of heterogeneity in the distribution of deaths in a cohort. If all individuals die at the same age, $H = 0$ and the shape of the survival schedule is rectangular. If all individuals have exactly the same probability of dying at each age, the shape of the survival schedule exponentially decreases and $H = 1.0$. The survival schedule for values of $H < 0.5$ is convex and the survival schedule is concave for values of $H > 0.5$ (Carey 2001). The inverse of life expectancy at age x ($\bar{\mu}_x$), is the average mortality experienced by the cohort beyond age x. Death distribution (d_x) is described as fraction of original cohort dying between x and x + 1. All these parameters and their formulae and descriptions came from Carey (2001).

Statistical Analysis. The data for the effects of different cultivars of canola (set as completely randomized design) on developmental time and adult longevity were subjected to one-way analysis of variance (ANOVA) to determine the similarities or significant differences using MINITAB, version 15 statistical software (Minitab Inc. 2007). Statistical differences among means were evaluated using Duncan's multiple test at $\alpha = 0.05$. The log-rank test (Rosner 2000) was used to survival curve analysis (Proc Lifetest, SAS Institute 2003). The values of $(1 - l_x)$ in each age class were used as status (probability of death) in the Lifetest program. The effects of canola cultivars on survival rate of diamondback moth immature throughout the developmental time were examined using linear regression analysis (Proc REG, SAS Institute 2003).

Results and Discussion

The effect of different canola cultivars on developmental time and adult longevity of *P. xylostella* (Tables 2 and 3) were similar to those reported for *P. xylostella* on canola (Ebrahimi et al. 2008, Golizadeh et al. 2009), cabbage (Campos 2008), and some *Brassica* vegetables (Syed and Abro 2003) in previous studies. Our developmental time data were much lower than those reported for *P. xylostella* on cabbage (28.84 ± 1.85 d) (Ahmad et al. 2008). The developmental times of *P. xylostella* reared on various canola cultivars differed significantly ($F = 11.24$; df = 9, 409; $P < 0.001$). No significant difference was observed for third instar and prepupal periods of *P. xylostella* on different canola cultivars. The egg incubation period was significantly different among the 10 canola cultivars, indicating that this parameter was affected by the host plant type on which adults developed. Our results for the incubation period (3.02–3.44 d) were greater than those reported by Golizadeh et al. (2009) for canola 'PF' (2.84 d), by Ebrahimi et al. (2008) for rapeseed (2.69–3.04 d), and by Campos (2008) on cabbage (3.00 d) under different photoperiod regimes. Our results for incubation period agreed with those reported by Ahmad et al. (2008) (3.27 d) on cabbage. Mean incubation period on Sarigol was found to be the shortest and significantly different from that on Licord, SLM_{046}, and Opera ($P < 0.001$) (Table 2). Larval ($P < 0.001$) and pupal ($P < 0.001$) period and total developmental time ($P < 0.001$) were significantly different among the canola cultivars. We reared 10 separate colonies of *P. xylostella* on 10 canola cultivars for more than two generations, and this can be a reason that plant cultivars affected this parameter, while at the first rearing generation effect of plant cultivar on incubation period was not significant (data not shown).

Both the larval period and the total developmental time were longest on Opera and shortest on $Hayula_{420}$. The larval period on RGS_{003} was not significantly different from those on Sarigol, Zarfam, Licord, or Talaye. The larval period of *P. xylostella* ranged from 7.68 d on $Hayula_{420}$ to 8.91 d on Opera and the variation can be attributed to differences in nutrients or secondary metabolites among different host plants.

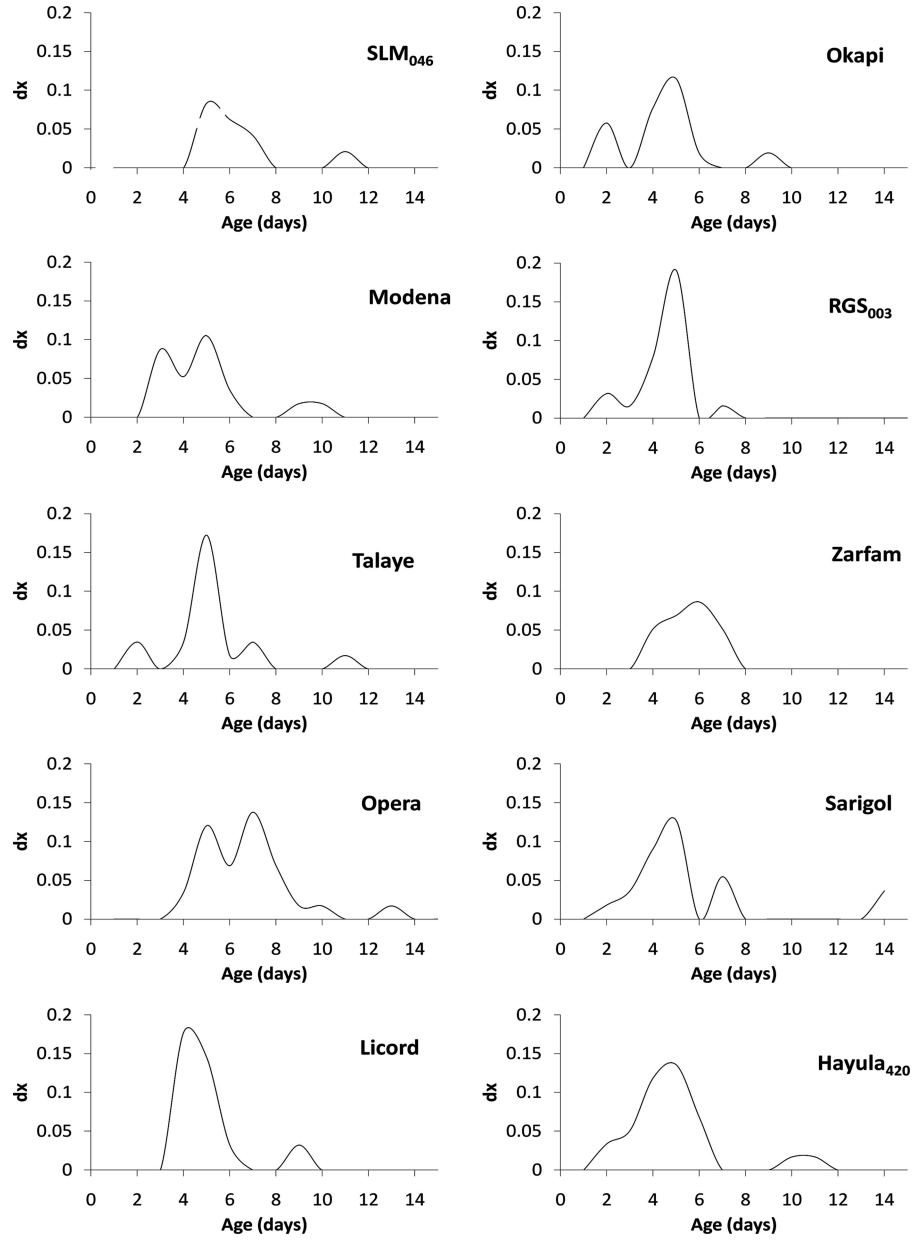

Fig. 1. Death frequency (d_x) of *P. xylostella* immature on ten canola cultivars in laboratory. Highest peak in each graph reveal the early stage cause-specific mortality (d_x is part of original cohort dying between two consecutive days).

The mean larval period was 8.29 d, which is lower than the value reported by Ahmad et al. (2008) on cabbage (11.29 d), by Ebrahimi et al. (2008) for rapeseed (11.03 d), and by Syed and Abro (2003) for some *Brassica* vegetable (>9 d), whereas our data were greater than those reported by Golizadeh et al. (2009) for canola PF (7.82 d), and similar to values reported by Campos (2008) on cabbage (8.8 d). These differences may be due to physiological differences depending on the type of the host plant, genetic variation as a result of laboratory rearing or variation due to geographic sources of the pest.

Different canola cultivars showed significant effects on the longevity of male ($F = 13.83$; df = 9, 155; $P < 0.001$) and female *P. xylostella* ($F = 11.75$; df = 9, 176; $P < 0.001$); the whole life span (egg hatching to adult mortality) was affected significantly by cultivar of canola (Table 3). The female whole lifespan was longest when the larvae were reared on $Hayula_{420}$ (25.1 d) and shortest on Okapi (19.5 d). The female longevity was significantly different among the 10 tested canola cultivars. Female longevity was shortest when the larvae were reared on Okapi (5.1 d) and longest on $Hayula_{420}$ (10.1 d) (Table 3). Female longevity in this

Table 4. Mortality parameters of *P. xylostella* on 10 canola cultivars under laboratory conditions

Canola cultivar	Mortality parameter			
	Entropy (H), survival schedule	Avg daily mortality ($\bar{\mu}_x$) for larvae instar	Immature max central death rate (m_x)	Age (d) and stage (immature stage) corresponds to max central death rate
SLM_{046}	0.243 < 0.5, convex(SC[a] I)	0.075, end of L1[b]	0.087	5, end of L1
Okapi	0.335 < 0.5, convex(SC I)	0.074, outset of L2	0.143	5, outset of L2
Modena	0.397 < 0.5, convex(SC I)	0.069, outset of L2	0.130	5, outset of L2
RGS_{003}	0.404 < 0.5, convex(SC I)	0.066, outset of L2	0.245	5, outset of L2
Talaye	0.343 < 0.5, convex(SC I)	0.073, outset of L2	0.204	5, outset of L2
Zarfam	0.335 < 0.5, convex(SC I)	0.063, outset of L2	0.103	6, outset of L2
Opera	0.500 = 0.5, concave(SC II)	0.089, outset of L2	0.195	7, outset of L2
Sarigol	0.395 < 0.5, convex(SC I)	0.070, outset of L2	0.161	5, outset of L2
Licord	0.447 < 0.5, convex(SC I)	0.086, end of L1	0.195	4, end of L1
$Hayula_{420}$	0.541 > 0.5, concave(SC III)	0.061, outset of L2	0.186	5, outset of L2

[a] SC, survivorship curve.
[b] L1 and L2 represent larvae instars I and II, respectively.

study were greater than those reported by Campos (2008) for cabbage (4.4 d) and was similar to those reported by Golizadeh et al. (2009) on canola PF under the same environmental conditions (male longevity, 6.40; female longevity, 8.33 d), by Ahmad et al. (2008) for cabbage (8.46 d), and these differences can be attributed to host plant type, although different geographical region may be a significant factor.

Most life tables have not included the effects of host plant quality and host plant defensive metabolites on herbivore mortality (Preszler and Price 1988, Price et al. 1990). For that reason, life tables may miscalculate the mortality from this potentially important factor. We recognized this by representing all age-independent mortality before natural age of death. An accidental mortality due to any reason before the natural age of dying (e.g., days 19–26 in our experiments) should be studied in more detail cause-specifically. It seems that in most previous studies, the effects of host plant quality on mortality of arthropods has been neglected by relating this kind of mortality to other causes, such as natural enemies.

Total mortality of *P. xylostella* (from egg to adult stage) was between 20.8 and 48.3% on all canola cultivars. Egg mortality was the lowest on SLM_{046} (3.6%) and the highest on $Hayula_{420}$ (15.7%). Mortality during first instar establishment averaged between 7.1 (Modena) and 25.7% (Opera and $Hayula_{420}$). Pupal mortality ranged between 0% (Okapi and RGS_{003}) and 9.1% (SLM_{046}). The maximum calculated value of $\bar{\mu}_x$ on canola cultivars was at days 5–7, i.e., at the outset of second stadium, when larvae tries to exit from leaf mines, and in laboratory is the most susceptible age of immatures (Fig. 1; Table 4). Zalucki et al. (2002) draw together literature on mortality of immature stages of Lepidoptera cause-specifically and found that after predation the most reported mortality factors are failure to establish and host-related factors including 28 reports among 141 reviewed studies. They reported 44% age-specific mortality ($100q_x$) for *P. xylostella* first/early instars, whereas in the current study highest mortality of early instars was 25.7% on Opera and $Hayula_{420}$.

In our previous study focusing on life table parameters of *P. xylostella* on different canola cultivars, we found that population on SLM_{046} will grow with an intrinsic rate of natural increase value of 0.304 ± 0.01 and that it was a relatively suitable host plant, whereas RGS_{003} had a 0.241 ± 0.004 ♀/♀/day rate of population increase (unpublished data) and was relatively unsuitable to *P. xylostella* feeding. In the present research we demonstrated similar patterns for preimaginal m_x which was calculated as the highest (0.245) and the lowest (0.087) probability of dying in the age interval 4–5 for RGS_{003} and SLM_{046} respectively. Thus, the relatively unsuitable cultivar (RGS_{003}) had the highest immature mortality and vice versa for suitable cultivar, i.e., SLM_{046}.

Larval survivorship (Table 5) decreased linearly with time significantly ($P < 0.001$) and at a constant rate, indicating that mortality rates do not vary with larval instar; although our data indicated accidental death at outset of second instar, which can be due to emergence from first instar mines that create an age-at-risk in larval stage as described above (Fig. 1). In addition to regression analysis (Table 5), survival curve analysis revealed no significant difference among 10 canola cultivars tested ($\chi^2 = 4.9265$, df = 9, $P > 0.05$).

Table 5. Regression analysis of survivorship of *P. xylostella* throughout the development time on 10 canola cultivars

Canola cultivar	Regression equation	R^2
SLM_{046}	$Y = 1.041 - 0.020X$[a]	0.856
Okapi	$Y = 0.992 - 0.025X$	0.796
Modena	$Y = 1.007 - 0.028X$	0.830
RGS_{003}	$Y = 0.984 - 0.027X$	0.722
Talaye	$Y = 1.019 - 0.028X$	0.820
Zarfam	$Y = 1.026 - 0.023X$	0.804
Opera	$Y = 1.090 - 0.044X$	0.887
Sarigol	$Y = 1.007 - 0.03X$	0.800
Licord	$Y = 1.024 - 0.036X$	0.784
$Hayula_{420}$	$Y = 1.025 - 0.043X$	0.843

[a] Regression models were significant in all analyses on 10 canola cultivars, $P < 0.001$.

The *H* value for the *P. xylostella* life table (Table 4) for SLM_{046} (0.243), indicated Deevey's type I survivorship curve and a more convex survival schedule than the other cultivars. The *H* values of Opera and $Hayula_{420}$ were 0.500 and 0.541, respectively. Thus, the entropy values indicate that the shape of the survival schedule for $Hayula_{420}$ is more concave than the survival schedule for Opera and the survival curve type of $Hayula_{420}$ and Opera are type III and II, respectively. On other cultivars, the survivorship schedules are convex and the survival curves are considered as type I.

Susceptible stages in life cycle of any insect pest can be a key target in population management with lower control costs. In the next stage of our research, we seek defensive plant characteristic(s) that can be developed in plant breeding programs to facilitate control of the pest. The values of the parameters obtained in the current study can be useful for comparison of *P. xylostella* performance between canola cultivars.

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