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Research Article

Effects of short-term heat shock of eggs on the development and fecundity of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)

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Abstract: It has been hypothesized that the survival, development, fecundity and even population expansion of insects are all affected significantly by extremely high temperature. The diamondback moth, *Plutella xylostell* (L.) (Lepidoptera: Plutellidae), is a serious and economically important pest of cruciferous crops throughout the word. In this research, the adult longevity and fecundity of *P. xylostella* were studied. After effect of heat shock stress, (30, 35 and 40 °C) for 2, 4, 6 and 8h, the experiments were conducted at 25±1 °C, 65±5% RH, and a photoperiod of 16:8 (L: D)h on *Brassica napus*. The developmental time of immature stages were significantly affected after heat shock temperatures (30 to 40 °C) when compared to the 25 °C control, but the developmental time of larvae did not differ significantly at 40 °C. The pupal development time differed significantly at heat shock temperatures, which the longest (6.13±0.05 days) at 30 °C for 2h. Heat shock temperature also had significant impact on adult longevity and fecundity of diamondback moth. The longest adult longevity for females and males was determined to be 14.47±1.04 and 11.04±0.95 respectively at 35 °C for 2h. The fecundity of females fluctuated significantly with increasing temperature stress. Our findings can be used to develop a more profound understanding on the potential for this insect to evolve in response to environmental temperature changes.

Keywords: *Plutella xylostella*, fecundity, longevity, heat shock temperature

Introduction

Organisms are often exposed to various environmental stresses such as heat, cold, desiccation, CO_2, heavy metals, and different chemical compounds (Lindquist, 1986; Hoffmann and Parsons, 1991; Krishna *et al.*, 1992; Ferrando *et al.*, 1995). Temperature is a dominant factor affecting growth, reproduction, and distribution of organisms (Precht *et al.*, 1973; Cossins and Bowler, 1987; Hochachka and Somero, 2002). High temperature is an adverse climatic factor that suppresses population expansion of insects in the field (Denlinger and Hallman, 1998; Bale *et al.*, 2002). Temperature extremes limit the geographic range of insect populations, either directly by killing insects or indirectly by limiting the range of host plants (Speight *et al.*,

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1999). In nature, insects frequently experience fluctuating temperature regimes, which may result in exposure to high temperatures that may alter physiological tolerance to environmental stresses (Terblanche *et al*., 2010), reduce survival, and affect population dynamics (Mironidis and Savopoulou-Soultani, 2010) and alter exclusion rhythm, morphology, longevity, fecundity, fertility, and generally result in reduced fitness (Yocum *et al*., 1994; Mahroof *et al*., 2005a; Jørgensen *et al*., 2006; Cui *et al*., 2008; Xie *et al*., 2008; Mironidis and Savopoulou-Soultani, 2010, Niedermager *et al.*, 2012). Insects are vulnerable to high temperatures because, as small poikilotherms, their body temperature is approximately the same as that of their environment and heat from the environment can quickly elevate insect's body temperature to lethal levels, while water balance at high temperatures complicates the situation (Rinehart *et al*., 2000). The influence of lethal temperature cannot be measured by the same direct methods that are appropriate for measuring the influence of temperature on the rate of development (Andrewartha, 1970). The effect of short-term high temperature stresses may be either beneficial or harmful depending on the level and duration of high temperature (Hoffmann *et al.*, 2003). Many studies have proven that short-term exposure to high temperatures may increase the heat tolerance of an organism (heat hardening; see Hoffmann *et al.*, 2003). For example, exposure of a population of *Drosophila melanogaster* to 29°C for up to several days helps them gain a higher thermotolerance (Levins, 1969). Treating 1-day-old adults of pea leafminer, *Liriomyza huidobrensis* (Diptera: Agromyzidae) (which are reared at 25–26°C) at 32 or 35°C for 4h was significantly increased their heat resistance (Huang *et al.*, 2007). Organisms have similar response mechanisms in response to some different low or modest level stresses. The short-term high temperature treatment often helps organisms to increase other stress tolerances known as cross protection, cross tolerance or cross resistance (Stebbing, 1981; Calabrese and Baldwin, 2003). Longevity, oviposition period, and fecundity of the cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), decreased after being exposed to high temperatures (40, 42.5, 45 and 46.5 °C) (Mironidis and Savopoulou-Soultani, 2010). In two whiteflies, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), egg hatch declined after maternal females experienced heat shock, indicating that the impact of heat shock continued into the next generation (Cui *et al*., 2008).

The diamondback moth, *P. xylostella* (L.) is the most destructive pest insect of cruciferous plants throughout the world. It has been recorded since 1746 and is believed, it has been originated in the Mediterranean region (Harcourt, 1954; 1962), which is also the place of origin of some of the important crucifer crops such as, *Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *botrytis*, *Brassica oleracea* var. *gongylodes*, *Brassica oleracea* var. *italic* and *Raphanus sativus* (Tsunoda, 1980). The global importance of *P. xylostella* is reflected in its control costs that are estimated to be approximately US$ billion annually (Talekar and Shelton, 1993).

Brassica vegetables are important vegetable crops that are cultivated in most parts of Tehran province of Iran. *Plutella xylostella* occurs annually throughout this province wherever brassicaceous crops are grown and causes substantial crop losses during outbreak years. This study provides new information on the effect of heat shock temperatures on the biology of *P. xylostella* on *B. napus* with the main objective to develop knowledge on the effects of heat shock temperatures on development, reproduction and longevity of *P. xylostella*.

Materials and Methods

Plant rearing

This study was carried out during 2013 in the Department of Entomology, College of Agriculture, Tarbiat Modares University, Iran. Canola cultivar was used in this study, *B. napus* (cultivar ‘Opera’), was obtained from the Karaj

Seed and Plant Research Institute and was sown in field soil and compost mixture (3: 1 soil: peat) in 20 cm diameter plastic pots in greenhouse and growth chamber. Plants were used for experiments at 10 to 12 leaf stage. The stock culture of *P. xylostella* was maintained in a growth chamber set at temperature of 25 ± 1 °C, 60 ± 5% RH and a photoperiod of 16: 8 (L:D) hours.

Diamondback moth colony

A stock culture of *P. xylostella* originally collected from *Brassica* fields of Shahr-e-Ray, adjacent to Tehran, during June 2013. Thirty pairs of pupae were put into a plastic container with lots of small round holes (1 mm diameter) on the lower side and 3 bigger round holes (10 mm diameter) in the lateral side of the wall. After pupation, the female and male adults mated and the eggs were laid on the inside wall. The first instar larvae dropped through the holes onto the leaves of rapeseed plant.

The insectary temperature was set at 25 ± 1 °C, 60 ± 5% RH and a photoperiod of 16:8 (L: D) h. Three small cottons wick soaked in 10% honey solution were placed in the large holes in the lateral side of the plastic container to provide a source of carbohydrate for adult feeding and the cotton was changed twice daily.

Effect of heat shock on the development and reproduction

Development time of *P. xylostella* was studied at temperature regimes (30, 35 and 40 °C) for 2, 4, 6 and 8 h, respectively. In all treatments, growth chamber was set at 60 ± 5% RH and a photoperiod of 16:8 (L: D) h. Among these treatments, the treatment of 25 °C was considered as control. After 12 h, the newly laid eggs of *P. xylostella* were taken from the surface of the host plant leaves using a fine camel's hair brush and were individually transferred into excised canola leaf discs placed on wet cotton wool in plastic container (9×5×4 cm) and then transferred to growth chambers. To facilitate ventilation, lids of plastic containers were covered with fine nylon mesh. At least 150 eggs were monitored at each heat shock temperatures. After the heat shock temperatures, the eggs of *P. xylostella* were checked daily, and the number of emerged larvae was recorded daily. The development of newly emerged larvae was monitored on fresh host plant foliage, which renewed every day until they dead or reached to the prepupal stage. Head capsule width or exuviae from moultings were used to discriminate the larval instars. When larvae became short and c-shaped, they were considered as having entered the prepupal stage. The emerged pupae were checked daily until all adults emerged or pupae died. The survival rate and development time were recorded for immature stages. For each temperature and each duration stress at least 15 male-female pairs of moth (replicate) that had emerged at the same stress temperature duration were used for mating and egg laying. This cage was a cubic Plexiglas container of 15 × 8 × 5 cm dimensions. The top of the containers were cut off and covered with micromesh screen for ventilation. There was an opening on one side of the each container for inserting and removing plant foliage. The host plant foliage was replaced with new ones every day and the numbers of eggs laid per each female were recorded daily.

Statistical analysis

Effect of heat shock temperatures on biological parameters of diamondback moth were analyzed using one-way ANOVA. If significant differences were detected, multiple comparisons were made using the Tukey test ($P < 0.05$). Statistical analysis was performed using SPSS statistical software. Data were checked for normality prior to analysis using Anderson-Darling method.

Results

Effect of heat shock on developmental time of *P. xylostella*

Data on the effect of heat shock temperatures on the development of *P. xylostella* is presented in Table 1. Heat shock

temperatures significantly affected the incubation period of eggs at 30 °C (F = 20.84; df = 4, 745; P < 0.05), 35 °C (F = 28.16; df = 4, 745; P < 0.05) and 40 °C (F = 11.01; df = 4, 745; P < 0.05). The shortest and longest incubation periods of eggs were observed at 30 °C for 4h (3.00 ± 0.02 days) and 35 °C for 2h (3.65 ± 0.04 days), respectively. The developmental time of larvae was not significantly differed at 40 °C. While heat shock temperatures significantly affected the developmental time of larvae at 30 °C (F = 13.71; df = 4, 719, P < 0.05) and 35 °C (F = 15.34; df = 4, 719; P<0.05). The pupal development time differed significantly after heat shock temperatures at 30 °C (F = 53.01; df = 4, 488; P < 0.05) and 40 °C (F = 15.70; df = 4, 439; P < 0.05) and the longest time (6.13±0.05 days) was observed at 30 °C for 2h.

Effect of heat shock on oviposition period, adult longevity and fecundity of *P. xylostella*

As shown in Table 2, the mean adult longevity (both for males and females) fluctuated significantly with increasing the time of exposure in all heat shock temperatures tested (30, 35 and 40 °C) and ranged from 11.04 days (at 35 °C for 2h) to 7.02 days (at 40 °C for 2h) for males and from 14.47 days (at 35 °C for 2h) to 7.60 days (at 40 °C for 2h) for females. There was no significant difference among females longevity after heat shock at 40 °C at different exposure times (F = 1.29; df = 4, 127; P = 0.275) (Table 2).

The pre-ovipositional periods of *P. xylostella* were not significantly different after heat shock at 30 °C (F = 0.87; df = 4, 204; P = 0.478) and 40 °C (F= 2.56; df = 4, 173; P= 0.040) and the pre-oviposition period ranged from 1.00 to 1.72 days but heat shock had influence on post-oviposition periods at 30 to 40 °C, and the longest was estimated to be 1.27 ± 0.32 at 35 °C for 2h.

The mean oviposition period of *P. xylostella* after heat shock temperatures differed significantly. The shortest and longest oviposition periods were indicated 6.00 ± 0.73 and 11.61 ± 0.86 days at 40 °C for 2h and 35 °C for 2h, respectively. The fecundity per female per day fluctuated significantly with the increasing heat shock temperature (Table 2). The fecundity per female indicted significant differences after heat shock at 30 °C (F = 34.38; df = 4, 182; P < 0.05), 35 °C (F = 21.85; df = 4, 196; P<0.05) and 40 °C (F= 3.73; df = 4, 96; P < 0.05) and the highest were indicated at 30 °C for 4h, 35 °C for 6h and 40 °C for 6h (Table 2).

Discussions

Ambient temperature is a key environmental factor influencing variety aspects of insect ecology and development (Deutsch *et al*., 2008). When temperatures exceed an insect's optimum temperature range, there are two mutually exclusive results: survival or death. Even if a species could survive after exposure to heat stress, fitness is probably affected (Scott *et al*., 1997; Rinehart *et al*., 2000; Cui *et al*., 2008; Zhou *et al*., 2010). Results obtained in this study revealed obvious effects of heat shock temperatures on development and fecundity of *P. xylostella*. Our results showed that the incubation periods of egg, larval, pupal developmental times and adult longevity of *P. xylostella* were not significantly affected with increasing heat shock temperatures. In addition adult longevity and fecundity of diamondback moth fluctuated with increasing heat shock temperatures. There was no significant differences among larva duration and female adult longevity at 40 °C. Our findings differs from the previous findings, that may be due to difference between insect species, temperature, exposure time and developmental stage of insect, (Ohgushi and Sawada, 1997; Scott *et al*., 1997; Harrington *et al*., 1999; Rinehart *et al*., 2000; Cui *et al*., 2008; Zhao *et al*., 2009). However, both adult longevity and fecundity of *Agasicles hygrophila* significantly decreased with increasing temperature (Zhao *et al*., 2009).

Table 1 Developmental time and adult longevity (days) (Mean±SE) of *P. xylostella* after their exposure to heat shock temperatures.

Temperature (˚C)	Duration of exposure (hour)	Incubation period	Larval development time	Pupal period	Female adult longevity	Male adult longevity
30	0	$3.25 \pm 0.04^{b(CDE)}$	$7.21 \pm 0.22b^{c(CD)}$	$4.15 \pm 0.09^{d(E)}$	$7.80 \pm 0.31^{b(C)}$	$5.79 \pm 0.29^{b(D)}$
		(n = 150)	(n = 143)	(n = 101)	(n = 50)	(n = 51)
	2	$3.01 \pm 0.02^{c(F)}$	$7.94 \pm 0.26^{b(BCD)}$	$6.13 \pm 0.05^{a(A)}$	$8.08 \pm 0.59^{b(C)}$	$7.29 \pm 0.42^{ab(BCD)}$
		(n = 150)	(n = 145)	(n = 111)	(n = 51)	(n = 51)
	4	$3.00 \pm 0.02^{c(F)}$	$7.03 \pm 0.34^{b(D)}$	$5.73 \pm 0.15^{ab(AB)}$	$8.60 \pm 0.74^{b(BC)}$	$9.44 \pm 0.60^{a(BCD)}$
		(n = 150)	(n = 145)	(n = 71)	(n = 25)	(n = 25)
	6	$3.25 \pm 0.05^{b(CDE)}$	$5.51 \pm 0.29^{c(ABC)}$	$5.26 \pm 0.12^{c(BC)}$	$7.90 \pm 0.48^{b(C)}$	$8.17 \pm 0.48^{ab(ABCD)}$
		(n = 150)	(n = 142)	(n = 95)	(n = 30)	(n = 30)
	8	$3.42 \pm 0.05^{a(BC)}$	$9.42 \pm 0.22^{a(AB)}$	$5.39 \pm 0.08^{bc(BC)}$	$12.28 \pm 1.14^{a(AB)}$	$9.61 \pm 0.89^{a(ABC)}$
		(n = 150)	(n = 148)	(n = 115)	(n = 53)	(n = 53)
35	0	$3.25 \pm 0.04^{b(CDE)}$	$7.21 \pm 0.22^{c(CD)}$	$4.15 \pm 0.09^{b(E)}$	$7.80 \pm 0.31^{b(C)}$	$5.78 \pm 0.29^{c(D)}$
		(n = 150)	(n = 143)	(n = 101)	(n = 50)	(n = 51)
	2	$3.65 \pm 0.04^{a(A)}$	$9.44 \pm 0.25^{a(A)}$	$5.41 \pm 0.09^{a(BC)}$	$14.47 \pm 1.04^{a(A)}$	$11.04 \pm 0.95^{a(A)}$
		(n = 150)	(n = 146)	(n = 109)	(n = 49)	(n = 49)
	4	$3.13 \pm 0.04^{b(EF)}$	$8.25 \pm 0.28^{b(ABCD)}$	$5.36 \pm 0.09^{a(BC)}$	$9.07 \pm 0.73^{b(BC)}$	$10.74 \pm 0.76^{ab(AB)}$
		(n = 150)	(n = 146)	(n = 89)	(n = 27)	(n = 27)
	6	$3.13 \pm 0.04^{b(EF)}$	$9.01 \pm 0.21^{ab(AB)}$	$5.31 \pm 0.10^{a(BC)}$	$8.85 \pm 0.79^{b(BC)}$	$8.13 \pm 0.54^{bc(ABCD)}$
		(n = 150)	(n = 142)	(n = 101)	(n = 39)	(n = 39)
	8	$3.19 \pm 0.04^{b\ (DEF)}$	$9.15 \pm 0.18^{a(AB)}$	$5.43 \pm 0.09^{a(BC)}$	$8.70 \pm 0.51^{b(BC)}$	$9.40 \pm 0.61^{ab(ABC)}$
		(n = 150)	(n = 146)	(n = 112)	(n = 47)	(n = 47)
40	0	$3.25 \pm 0.04^{bc(CDE)}$	$7.21 \pm 0.22^{a(CD)}$	$4.15 \pm 0.09^{c(E)}$	$7.80 \pm 0.31^{a(C)}$	$5.78 \pm 0.29^{b(D)}$
		(n = 150)	(n = 143)	(n = 101)	(n = 50)	(n = 51)
	2	$3.11 \pm 0.03^{(EF)}$	$7.48 \pm 0.25^{a(CD)}$	$5.04 \pm 0.10^{ab(CD)}$	$7.60 \pm 0.73^{a(C)}$	$7.02 \pm 0.64^{ab(CD)}$
		(n = 150)	(n = 141)	(n = 105)	(n = 48)	(n = 47)
	4	$3.47 \pm 0.05^{a(AB)}$	$7.49 \pm 0.33^{a(CD)}$	$5.19 \pm 0.15^{a(CD)}$	$9.82 \pm 1.02^{a(BC)}$	$8.64 \pm 0.99^{a(ABCD)}$
		(n = 150)	(n = 132)	(n = 70)	(n = 22)	(n = 22)
	6	$3.36 \pm 0.05^{ab(BCD)}$	$8.14 \pm 0.31^{a(ABCD)}$	$4.77 \pm 0.09^{b(D)}$	$8.69 \pm 0.80^{a(BC)}$	$9.38 \pm 0.87^{a(ABC)}$
		(n = 150)	(n = 125)	(n = 84)	(n = 29)	(n = 29)
	8	$3.28 \pm 0.04^{b(CDE)}$	$7.48 \pm 0.66^{a(CD)}$	$4.95 \pm 0.01^{ab(CD)}$	$7.79 \pm 0.84^{a(C)}$	$7.25 \pm 0.63^{ab(CD)}$
		(n = 150)	(n = 132)	(n = 84)	(n = 28)	(n = 28)

The means followed by same small letters in column at each temperature are not significantly different at ($P < 0.05$; Tukey-test).
The means followed by same capital letters in each column are not significantly different at ($P < 0.05$; Tukey-test).

Table 2 Oviposition period and fecundity (Mean ± SE) of *P. xylostella* after their exposure to heat shock temperatures.

Temperature (˚C)	Duration of exposure (hour)	Pre-oviposition period	Oviposition period	Post-oviposition period	Fecundity per female per day
30	0	$1.54 \pm 0.14^{a(A)}$ (n = 51)	$4.73 \pm 0.39^{b(C)}$ (n = 51)	$1.43 \pm 0.22^{a(A)}$ (n = 51)	$10.60 \pm 0.70^{c(CD)}$ (n = 47)
	2	$1.25 \pm 0.15^{a(A)}$ (n = 51)	$6.37 \pm 0.59^{b(C)}$ (n = 51)	$0.66 \pm 0.11^{ab(ABC)}$ (n = 51)	$15.55 \pm 0.88^{ab(AB)}$ (n = 47)
	4	$1.72 \pm 0.16^{a(A)}$ (n = 25)	$6.44 \pm 0.70^{b(C)}$ (n = 25)	$0.24 \pm 0.13^{b(C)}$ (n = 25)	$16.34 \pm 1.17^{a(AB)}$ (n = 19)
	6	$1.50 \pm 0.16^{a(A)}$ (n = 30)	$5.86 \pm 0.43^{b(C)}$ (n = 30)	$0.60 \pm 0.21^{b(ABC)}$ (n = 30)	$12.86 \pm 0.95^{bc(BCD)}$ (n = 26)
	8	$1.44 \pm 0.13^{a(A)}$ (n = 53)	$10.43 \pm 1.08^{a(AB)}$ (n = 53)	$0.49 \pm 0.15^{b(ABC)}$ (n = 53)	$10.52 \pm 0.52^{c(CD)}$ (n = 50)
35	0	$1.55 \pm 0.15^{a(A)}$ (n = 51)	$4.73 \pm 0.39^{b(C)}$ (n = 51)	$1.43 \pm 0.22^{a(A)}$ (n = 51)	$10.60 \pm 0.70^{cd(D)}$ (n = 47)
	2	$1.51 \pm 0.17^{ab(A)}$ (n = 49)	$11.61 \pm 0.86^{a(A)}$ (n = 49)	$1.27 \pm 0.32^{a(AB)}$ (n = 49)	$9.19 \pm 0.61^{d(AB)}$ (n = 49)
	4	$1.19 \pm 0.19^{ab(A)}$ (n = 27)	$7.85 \pm 0.75^{b(ABC)}$ (n = 27)	$0.07 \pm 0.05^{b(C)}$ (n = 27)	$15.06 \pm 0.75^{ab(AB)}$ (n = 24)
	6	$1.18 \pm 0.12^{ab(A)}$ (n = 39)	$7.54 \pm 0.76^{b(BC)}$ (n = 39)	$0.15 \pm 0.08^{b(C)}$ (n = 39)	$16.49 \pm 0.88^{a(AB)}$ (n = 36)
	8	$1.00 \pm 0.00^{b(A)}$ (n = 47)	$7.38 \pm 0.53^{bc(BC)}$ (n = 47)	$0.21 \pm 0.13^{b(BC)}$ (n = 47)	$12.75 \pm 0.77^{bc(BCD)}$ (n = 46)
40	0	$1.55 \pm 0.15^{a(A)}$ (n = 51)	$4.73 \pm 0.39^{b(C)}$ (n = 51)	$1.43 \pm 0.22^{a(A)}$ (n = 51)	$10.60 \pm 0.70^{c(CD)}$ (n = 47)
	2	$1.25 \pm 0.11^{a(A)}$ (n = 48)	$6.00 \pm 0.73^{ab(C)}$ (n = 48)	$0.33 \pm 0.12^{b(BC)}$ (n = 48)	$12.66 \pm 0.61^{bc(BCD)}$ (n = 44)
	4	$1.00 \pm 0.06^{a(A)}$ (n = 22)	$8.09 \pm 1.01^{a(AB)}$ (n = 22)	$0.68 \pm 0.32^{ab(ABC)}$ (n = 22)	$14.26 \pm 1.08^{ab(ABC)}$ (n = 19)
	6	$1.45 \pm 0.22^{a(A)}$ (n = 22)	$7.18 \pm 0.78^{ab(BC)}$ (n = 22)	$0.21 \pm 0.15^{b(C)}$ (n = 22)	$17.44 \pm 1.07^{a(A)}$ (n = 30)
	8	$1.00 \pm 0.00^{a(A)}$ (n = 22)	$6.64 \pm 1.06^{ab(BC)}$ (n = 22)	$0.29 \pm 0.13^{b(C)}$ (n = 22)	$15.11 \pm 1.12^{ab(AB)}$ (n = 26)

The means followed by same small letters in column at each temperature are not significantly different at (P<0.05; Tukey-test)
The means followed by same capital letters in each column are not significantly different at (P<0.05; Tukey-test)

Zhou *et al.* (2010) reported that the adult longevity and fecundity of *Opherella Communa* (Coleoptera: Chrysomelidae) significantly decreased with increasing short-term stress temperature. In addition results of Zhou *et al.* (2010) are partially agreed with the previous studies (Scott *et al*., 1997; Rinehart *et al*., 2000; Cui *et al*., 2008; Zhao *et al*., 2009, Zhou *et al*.,

2010). The incubation period of eggs and larval developmental time of *O. communa* increased with increasing short-term stress temperature (Zhou *et al.*, 2010). Cui *et al.* (2008) found that female fecundity of *B. tabaci* was not significantly different when adults were heat shocked at different temperatures but the high temperatures significantly reduced the number of eggs laid by the females of *T. vaporariorum* while no nymphs were hatched at 43 °C. Mironidis and Savopoulou-soultani (2010), also reported that the mean adult longevity of *Helicovrpa armigera* (Lepidoptera: Noctuidae) significantly declined with increasing exposure time at all heat shock treatments tested and the values of fecundity were found to be inversely related to the exposure time of adults to high temperatures, no eggs were laid by females of *H. armigera* at 40, 42.5 and 45 °C for 360, 120, and 15 min, respectively. Rinehart *et al.* (2000) revealed that the heat shock of adults of both sexes of *Sarcophaga crassipalpis* Macquart (Diptera: Sarcophagidae) at 45 °C for 60 min severely affected fecundity specifically, the number of eggs produced was significantly reduced to 90% in comparison to untreated flies (25 °C) and none of the eggs were fertilized, in contrast to finding at 45 °C for 25 min or at 40 °C for 120 min. Denlinger *et al.* (1991) found that for the same species the exposure of pupae or adults to 50 °C for 120 min caused their immediate death. Saxena *et al.* (1992) also reported that the exposure of three stored-product insect pests (e.g. *Callosobruchus chinensis* L. (Coleoptera: Bruchidae), *Trogoderma granarium* Everts (Coleoptera: Dermestidae) and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae)) in pupal stage to 45 °C for 48 or 72 h significantly affected the egg laying and hatching. No eggs were produced when pupae were exposed to 45 °C for 48 h.

Our findings showed that fitness of *P. xylostella* significantly increased with increasing temperature from 30 to 35 °C, but the fitness significantly decreased at 40 °C. There are two modes of killing by heat stress: one mod is characterized by rapid death and the other mode is characterized by delayed death caused by heat injury, whose effects could accumulate slowly and be displayed at later stages of development (Xie *et al*., 2008). There was no study on the effect of short-term high temperature stress on biological characteristics of *P. xylostella* in Iran. Therefore, the result of this study may be used for predicting population dynamics, distribution and dispersal of this insect.

In many insect species, high temperatures disrupt the normal functioning of the reproductive system in both sexes (Arbogast, 1981; Saxena *et al*., 1992; Mahroof *et al*., 2005b; Cui *et al*., 2008). It has been reported that heat shock can cause injury to oocytes and ovarian development in females that could lead to a decrease in egg production. Furthermore, heat shock usually affects male more than female reproductive functions due to direct injury to the testes and sperm (Chihrane and Lauge, 1994, 1997; Krebs and Loeschcke, 1994; Scott *et al*., 1997; Rinehart *et al*., 2000; Giojalas and Catala, 1993; David *et al*., 2005).

Biochemical changes like the inhibition of biosynthesis of a lot of physiological proteins or the synthesis of heat shock proteins can be detected in response to mild thermal stresses. The intensity of the expression of heat shock proteins depends on the temperature and the duration of the exposure as well as on the developmental stage and diapause status of the organism (Mahroof *et al*., 2005b; Teixeira and Polavarapu, 2005; Kalosaka *et al*., 2009). For most organisms, heat shock proteins are synthesized when ambient temperatures exceed the normal temperature optimum of the organism (Parsell and Lindquist, 1993) and the difference in tolerance between organisms may be related to differences in their optimal temperature for the heat shock protein-induction response (Lindquist, 1986; Goto *et al*., 1998).

In conclusion, knowledge of how heat shock temperatures influences the biological characteristics of the *P. xylostella* can help us to understand the population dynamics and management of this insect. Furthermore, several

P. xylostella life history parameters (i. e., survival, developmental time, adult longevity, reproduction and population growth parameters especially intrinsic rate of increase) on experimental heat shock temperatures, can be used for potential of *P. xylostella* to evolve in response to environmental changes. After laboratory studies, more attention should be devoted to semi-field and field experiments to obtain more applicable results in field condition.

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اثر شوک گرمایی کوتاه‌مدت تخم بر رشد و نمو و باروری شب‌پره پشت الماسی *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)

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چکیده: این فرضیه وجود دارد که بقاء، رشد و نمو، باروری و افزایش جمعیت حشرات به‌طور معنی‌داری تحت تأثیر دما قرار می‌گیرد. شب‌پره پشت الماسی *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) مهم‌ترین و مخرب‌ترین آفت خانواده چلیپائیان در سرتاسر دنیا می‌باشد. در این تحقیق، اثر شوک گرمایی بر طول عمر مراحل مختلف رشدی، حشرات کامل و باروری *P. xylostella* مورد مطالعه قرار گرفت. آزمایش‌ها بعد از شوک گرمایی در شرایط دمایی ۱ ± ۲۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۶۵ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی روی گیاه کلزا *Brassica napus* انجام شد. دوره رشد و نمو مراحل قبل از بلوغ بعد از شوک گرمایی (°C ۳۰، ۳۵ و ۴۰) در مقایسه با دمای ۲۵ درجه سلسیوس، به‌طور معنی‌داری تحت تأثیر قرار گرفتند. طول دوره لاروی در شوک گرمایی ۴۰°C تحت تأثیر مدت زمان استرس قرار نگرفت. هم‌چنین شوک گرمایی بر طول دوره شفیرگی به‌طور معنی‌داری مؤثر بود. بیشترین طول دوره شفیرگی (۰/۰۵ ± ۶/۱۳ روز) در استرس گرمایی ۳۰ درجه سلسیوس به‌مدت ۲ ساعت به‌دست آمد. شوک گرمایی بر باروری و طول عمر حشرات کامل شب‌پره پشت الماسی تأثیر معنی‌دار داشت. بیشترین طول عمر حشرات کامل ماده (۱/۰۴ ± ۱۴/۴۷ روز) و نر (۰/۹۵ ± ۱۱/۰۴ روز) در استرس گرمایی ۳۵ درجه سلسیوس به‌مدت ۲ ساعت مشاهده شد. میزان باروری ماده‌ها با افزایش شوک‌های گرمایی به‌طور معنی‌داری نوسان داشت. یافته‌های این تحقیق می‌تواند به درک عمیق‌تر از پتانسیل حشرات نسبت به تغییرات محیطی مورد استفاده قرار بگیرد.

واژگان کلیدی: *Plutella xylostella* ، باروری، طول عمر، شوک گرمایی