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Research Article

Effect of short-term high temperature stress on demographic parameters of *Plutella xylostella* (Lepidoptera: Plutellidae)

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Abstract: Organisms are often exposed to various stresses such as heat. The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is a serious pest of cruciferous crops in Iran and the world. The effect of short-term temperature stress on egg stage of *P. xylostella* and its demographic parameters were studied under laboratory conditions. Diamondback moth eggs were exposed to 30, 35 and 40 °C for durations of 2, 4, 6, 8 h and then returned to normal temperature condition (25 °C). The results showed that *P. xylostella* eggs successfully developed to adulthood at short-term (2, 4, 6 and 8 h) high temperatures stress. The ovipositional period was significantly longer at 30 °C for 8 h, 35 °C for 2 h and 40 °C for 4 h than for other periods of stress. There is a significant difference in the net reproduction rate (R_0) among the short-term high temperature stresses treatments. The highest and lowest R_0 was obtained at 30 °C for 8 and 4 h, respectively. The intrinsic rate of increase (r_m) was also found to be significantly affected by stress temperatures. The r_m-value ranged from 0.15 ± 0.009 (30 °C for 4 h) to 0.22 ± 0.004 (35 °C for 8 h). Knowledge of the effect of temperature on demographic parameters of *P. xylostella* could be useful in the integrated pest management for forecasting the population dynamics of this economic pest of brassicas, thereby reducing insecticide inputs, negative environmental impacts and saving hundreds of millions of dollars annually.

Keywords: Diamondback moth, Demography, crucifers, population fluctuation, Short-Term High Temperature.

Introduction

Insect development occurs within a specific temperature range and as such, temperature is considered as the most important abiotic factor that affects distribution, colonization, survival, abundance, behaviour, fitness and the life history of insects in general (Hallman and Denlinger, 1998; James *et al*., 2002; Hoffmann *et al*., 2003, 2012; Geister and Fischer 2007; Berger *et al*., 2008; Forster and Hirst, 2012). The frequency and duration of periods with hot d have increased around the globe in recent decades e.g. Europe (Beniston, 2004), Australia (Pezza *et al*., 2012), Russia (Trenberth and Fasullo, 2012), China (Huang *et al*., 2010), and this trend is expected to continue under global warming (IPCC, 2013). Temperature plays an important role in the biological functions of organisms from the molecular to ecosystem level (Hochachka and Somero, 2002), and can

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determine the niche of a species recognizing as a key factor driving the dynamics and distributions of natural populations (Savage *et al*., 2004; Paaijmans *et al*., 2013; Ma *et al*. 2015). Insects are vulnerable to high and fluctuating temperature that may include heat shock conditions (Rinehart *et al*., 2000; Cui *et al*., 2008). Sensitivity to fluctuations in temperature can cause changes in physiological, biochemical and ecological responses (Armstrong, 1992). The suitable temperature for most insect species ranges from 25 to 35 °C (Arbogast, 1981). Higher or lower temperatures adversely affecting the growth and development of insect, while long-term exposure to temperatures exceeding 40 to 45 °C can be lethal. This low resistance to temperature extremes is widely used as a basis for effective and ecologically safe control method of insect pests (Arbogast, 1981). High temperatures tend to kill insect cells by denaturing proteins, altering membrane and enzyme structures and properties, and through the loss of water (dehydration), as such, high temperatures offer rich potential for pest management strategies (Gullan and Cranston, 2005). Some research showed that short-term high temperatures can significantly affect individual development, survival, fecundity and physiological metabolism in insects (e.g., Ohgushi and Sawada, 1997; Denlinger and Hallman, 1998; Cui *et al.,* 2008; Zhao *et al.,* 2009). In general, the effect of high temperature heat shocks may be either beneficial or harmful, depending on the level and duration. Many studies have shown that brief exposure to a high temperature may increase the heat tolerance of an organism (heat hardening, see Hoffmann *et al.,* 2003). For example, when *Drosophila melanogaster* (Meigen) were exposed to 29 °C for up to several d they developed a higher thermo tolerance (Levins, 1969). Insects can avoid thermal stress by escaping, e.g., migration or changing activity patterns, or continuously adapting (genetically or phenotypically) to the stress condition through selection or by plastic responses, e.g., by change in skin morphology, life history or physiology (Hoffmann *et al.,* 2003; Overgaard and Sørensen, 2008). In such cases, stress response is of great ecological importance not only for survival, but also for keeping reproductive characteristics functioning in populations of small arthropods living in unpredictable environments (Jørgensen *et al.,* 2006). Insects that are exceedingly sensitive to high temperatures can be immediately killed if they are exposed to extremely short-term high temperature (Cui *et al.,* 2008; Zhao *et al.,* 2009). Some insect species fail to emerge from pupae after experiencing heat shock, such as *Sarcophaga crassipalpis* Macquart and *D.melanogaster* (Denlinger *et al.,* 1991). Developmental abnormalities and phenocopy mutations were observed in *D. melanogaster* and some *Aedes* spp. That experienced heat stress (Anderson and Horsfall, 1963). Development and fecundity of *Bemisia tabasci* (Gennadius) type-B, *Ephestia cautella* Walker, *Plodia interpunctella* (Hubner) and *Agasicles hygrophila* Selman and Vogt, were reduced by exposure to high temperatures (Arbogast 1981; Cui *et al.,* 2008; Zhao *et al.,* 2009; Guo, *et al*., 2013), on the contrary, *Bactrocera oleae* showed high survival percentages of larvae and adults at temperatures up to 38 °C, and pupae had a relatively increased heat tolerance up to 40 °C (Pappas *et al*., 2011). In addition, extremely high temperature can induce sterility in male insects, for example in *Drosophila buzzatii* Patterson and Wheeler, *Ceratitis capitata* Wiedemann and *Aedes* mosquitoes (Vollmer *et al.,* 2004).

Plutella xylostella (L.) (Lepidoptera: Plutellidae), is a major cosmopolitan pest of *Brassica* and other crucifer crops all over the world. It is distributed throughout different climatic areas including tropical, subtropical and temperate zones, and has the ability to migrate among different climatic zones (Chapman *et al.,* 2002; Coulson *et al.,* 2002).The total annual cost for *P. xylostella* control throughout the world surpasses one billion US dollars (Roux *et al.,* 2007). Population parameters are important in the measurement of population growth capacity of a species under specified conditions. These parameters are also used as indices of population growth, the rates responding to

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selected conditions and as bioclimatic indices of assessing the potential for pest population growth in a new area (Southwood and Henderson, 2000). The most favourable temperature for the growth and development of *P. xylostella* is 25 °C, while temperatures higher than 30 °C or lower than 20 °C are harmful (Shirai, 2000; Liu *et al.,* 2002).

The present paper was designed to study the effect of short-term exposure of *P. xylostella* eggs to high temperature stress to discover how the demographic parameters of *P. xylostella* is effected by short-term high temperature stress following transfer to normal temperature conditions.

Materials and Methods

Plants and Insects

In this study, seeds of canola, *Brassica napus* (cultivar 'Opera'), was obtained from the Seed and Plant Improvement Institute in Karaj, Iran. Host plant seeds were planted in greenhouse conditions (25 ± 5 °C, 70 ± 5% RH and a photoperiod of 16 L: 8 D h.) using field soil and a compost mixture (3:1 soil: peat) in 20 cm diameter plastic pots without the use of any fertilizer. Every two weeks, canola plants were used for conducting the experiments. The initial population of *P. xylostella* was collected from canola fields in Shahr- e- Rey, Tehran Province, during June 2013. The stock culture of *P. xylostella* was maintained in a growth chamber set at laboratory conditions.

Thirty pairs of pupae were put into a plastic container with many small round holes (1 mm diameter) at the bottom and three bigger round holes (10 mm diameter) on the lateral side of the container. Following pupation, the female and male adults mated and eggs were laid on the inside wall. The hatched first instar larvae dropped through the holes onto the leaves of the canola plant, *B. napus* (cultivar 'Opera') growing in 20 cm diameter pots under the plastic containers. The insectaria temperature was set at laboratory condition. 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 renewed every day.

Life table parameters

Plutella xylostella adults from the stock culture were paired and 10 pairs were placed in the plastic containers (15 × 8 × 5 cm diameter) for oviposition. The eggs (age < 1 2 h) were taken from the surface of the host plant's leaves using a small brush and placed individually in a plastic container (9 × 5 × 4 cm diameter) on a leaf of the host plant. The host plant foliage were inserted in water-soaked cotton to maintain freshness. To facilitate ventilation, the lid of the plastic container was covered with a fine nylon mesh. At least 150 eggs of *P. xylostella* were used at each temperature (25, 30, 35 and 40 °C) for 2, 4, 6, and 8 h, respectively. Irrespective of the temperature, the growth chamber was set at a relative humidity of 60 ± 5% RH and a photoperiod of 16 L: 8 D h. and the treatment of 25 °C was considered as the control.

Following the high temperature stress, the eggs were checked daily and the development stages were recorded. The larvae were fed on fresh host plant leaves. The leaves were replaced with fresh ones every day until the larvae were dead or reached the prepupal stage. The presence of exuviae was used to discriminate the larval instars. The regular checking was continued until all adults emerged or pupae died. The survival rate and development time were recorded for all immature stages. The sex ratio of emerged adults from larvae reared at different temperature stresses was determined. Based on the data of the incubation period of eggs, the duration of larval and pupal stages, pre-oviposition period, age specific mortality/survivorship and fecundity, a fertility life table was constructed according to Birch (1948) and Carey (1993, 2001).

Plutella xylostella reproduction was studied at each heat shock temperatures. For the temperature of each stress duration, at least 15 pairs (replications) that had emerged at the same temperature during the stress duration were used

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for mating and egg laying. This cage was a cubic Plexiglas container of 15 × 8 × 5 cm diameter. The top of this container was cut off and covered with fine mesh gauze. The host plant foliage was replaced with new ones every day and the numbers of eggs laid per each female were recorded daily. This daily monitoring continued until the deaths of adult moth. The following population growth parameter was applied using a formula suggested by Carey (1993): intrinsic rate of increase (r_m), mean generation time (T), finite rate of increase (λ), doubling time (DT) and net reproduction rate (R_0).

Statistical analysis

Data were tested for normality using the Kolmogorov-Smirnov test. The mean values of (n-1) Jackknife pseudo-values for each temperature and duration time were subjected to analysis of (ANOVA). Data were submitted to one-way ANOVA for assessing their significance. If significant differences were present, multiple compressions were made using the Tukey test procedure. Statistical analysis was performed by using the SPSS V.20 and SAS 9.2 statistical packages. Differences in R_0, T, λ, DT and r_m values were tested for significance by estimating variances using the Jackknife procedure (Meyer *et al.,* 1986; Maia *et al.,* 2000). The Jackknife technique was also used to calculate the variance within population growth parameters. This technique is based on repeated calculation of the required estimator, missing out each sample in turn (Maia *et al.,* 2000).

Results

Survivorship, mortality and fecundity

Plutella xylostella successfully developed to adulthood at short-terms (2, 4, 6, and 8 h)

The shortest and longest survivorship periods for females and males were observed at 30 °C for 6 (32 and 32 d) and 8 h (52 and 38 d), respectively (Fig. 1). Short-term high temperature stresses significantly affected the survival rate from egg to adult emergence. The lowest and highest survival rate at the adult emergence were 34% (40 °C for 4) and 69% (30 °C for 2 and 8 h, 35 °C for 8 h), respectively.

The longest life expectancy (e_x) of new laid eggs females and males was indicated at 35 °C for 2 h (25.33 and 21.56 d) then the shortest life expectancy (e_x) of new laid eggs females and males was observed at 40 °C for 4 h (14.83 and 13.95 d). The longest and shortest life expectancy of the one-day-old adults (females and males) were estimated to be (8.67 and 6.75 d) at 40 °C for 8 h and (17.03 and 10.25 d) at 35 °C for 2 h, respectively (Fig. 2). The shortest and longest duration of oviposition period of females per day were estimated (13.5 (40 °C for 2 h) and 17.5 (30 °C for 6 h), respectively. The fecundity of females was significantly affected with the rise in stress temperature (Table 1). Short-term high temperature stress significantly affected the gross fecundity rate (mean number of egg/ female/ generation) 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 ($F = 13.73$, df = 4, 196, $P < 0.05$) (Table 1). Gross fecundity rate was highest at 30 °C for 8 h (311.4 ± 15.58 mean number of egg/ female/ generation), 35 °C for 6 h (313.38 ± 16.80 mean number of egg/ female/ generation) and 40 °C for 8 h (240.47 ± 12.64 mean number of egg/ female/ generation) (Table 1). Short-term high temperature stress also effected the net fecundity rates at 30 °C ($F = 14.26$, df = 4, 189, $P < 0.05$), 35 °C ($F = 10.49$, df = 4,199, $P < 0.05$) and 40 °C ($F = 2.06$, df = 4, 167, $P < 0.05$), then the net fecundity rates were highest at 30 °C for 8 h (124.09 ± 9.49 egg), 35 °C for 2 h (147.23 ± 10.77 egg) and 40 °C for 2 h (79.86 ± 7.40 egg) (Table 1). Short-term high temperature stress, showed significant effects on the mean fertile eggs per female per day at 30 °C ($F = 11.05$, df = 4, 184, $P < 0.05$), 35 °C ($F = 15.68$, df = 4, 197, $P < 0.05$) and 40 °C ($F = 9.44$, df = 4, 161, $P < 0.05$), which ranged from 8.94 to 15.94 (egg/ female/ day) at 35 °C for 2 h and 6 h, respectively (Table 1). *P. xylostella* females laid most eggs during the early ovipositional periods and were significantly greater in number at 30 °C for 8 h, 35 °C for 2 h and 40 °C for 4 h (Fig. 3).

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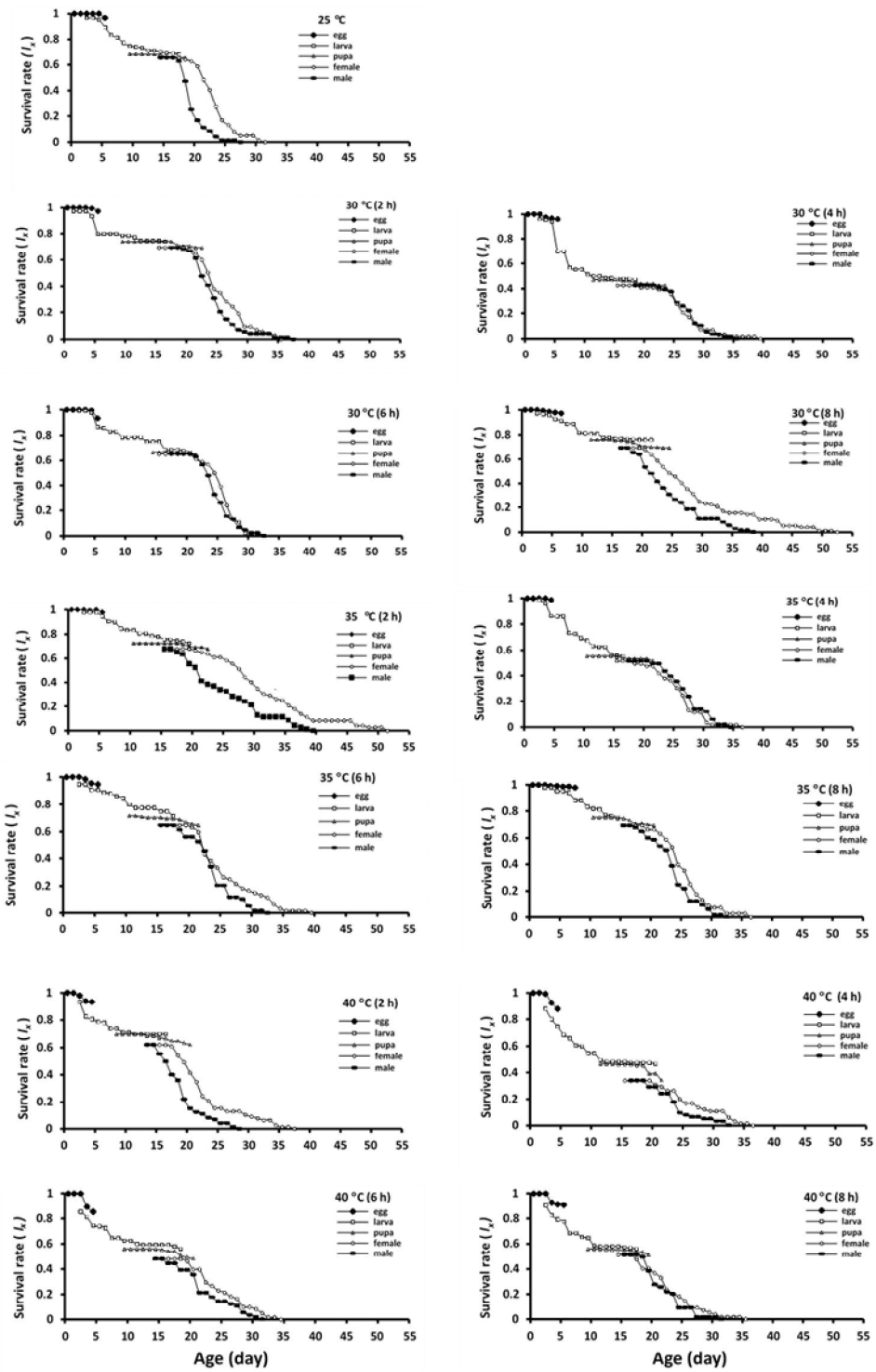

Figure 1 Survival rate (l_x) of *Plutella xylostella* (males and females) after their exposure to short-term high temperature stress.

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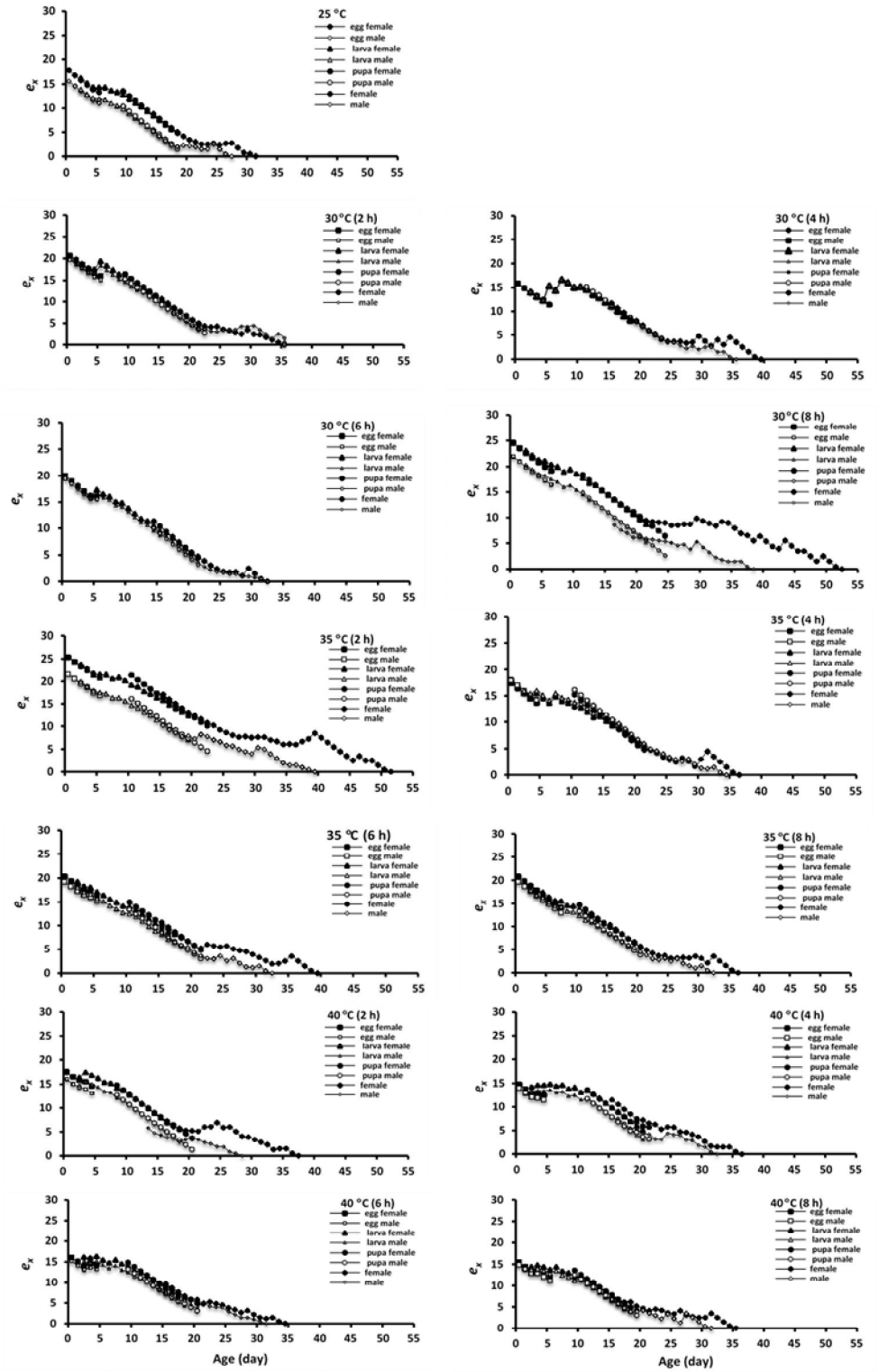

Figure 2 Life expectancy (e_x) of *Plutella xylostella* (males and females) after their exposure to short-term high temperature stress A (30 °C), B (35 °C) and C (40 °C).

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Table 1 The reproductive parameters of *Plutella xylostella* in short-term high temperature stress.

Temp. (°C)	Exposure time (h)	Gross fecundity rate	Gross fertility rate	Gross hatch rate	Net fecundity rate	Net fertility rate	Mean fertile eggs / female / d
30	0	137.82 ± 17.9$^{a(D)}$ (n = 47)	132.32 ± 9.23$^{a(DE)}$ (n = 48)	0.98	73.80 ± 6.31$^{b(DEF)}$ (n = 48)	72.33 ± 6.18$^{b(DEFG)}$ (n = 48)	10.38 ± 0.69$^{c(CD)}$ (n = 47)
	2	222.04 ± 11.05$^{b(C)}$ (n = 45)	214.63 ± 10.68$^{b(BC)}$ (n = 45)	0.96	120.27 ± 7.65$^{a(ABC)}$ (n = 48)	116.26 ± 7.40$^{a(ABC)}$ (n = 48)	15.03 ± 0.58$^{ab((AB)}$ (n = 47)
	4	245.20 ± 17.60$^{b(ABC)}$ (n = 19)	237.03 ± 17.01$^{b(ABC)}$ (n = 19)	0.96	56.76 ± 6.53$^{b(EF)}$ (n = 22)	54.87 ± 6.31$^{b(FG)}$ (n = 22)	15.80 ± 1.13$^{a(AB)}$ (n = 19)
	6	141.53 ± 10.49$^{a(D)}$ (n = 26)	131.15 ± 9.72$^{a(E)}$ (n = 26)	0.92	67.66 ± 53.6$^{b(DEF)}$ (n = 28)	61.22 ± 6.01$^{b(FG)}$ (n = 28)	11.92 ± 0.88$^{bc(BCD)}$ (n = 26)
	8	311.44 ± 15.58$^{a(AB)}$ (n = 50)	305.21 ± 15.27$^{a(A)}$ (n = 50)	0.98	124.09 ± 9.49$^{a(AB)}$ (n = 48)	123.67 ± 9.26$^{a(AB)}$ (n = 48)	10.52 ± 0.52$^{c(CD)}$ (n = 50)
35	0	137.82 ± 9.17$^{a(D)}$ (n = 47)	132.32 ± 9.22$^{a(DE)}$ (n = 48)	0.98	73.80 ± 6.31$^{b(DEF)}$ (n = 48)	72.33 ± 6.18$^{b(DEFG)}$ (n = 48)	10.38 ± 0.69$^{cd(CD)}$ (n = 47)
	2	268.69 ± 17.39$^{ab(AC)}$ (n = 48)	268.41 ± 17.95$^{ab(AB)}$ (n = 49)	0.97	147.23 ± 10.77$^{a(A)}$ (n = 48)	143.31 ± 10.48$^{a(A)}$ (n = 48)	8.94 ± 0.59$^{d(D)}$ (n = 49)
	4	256.02 ± 12.85$^{ab(AC)}$ (n = 24)	252.61±12.67$^{ab(ABC)}$ (n = 24)	0.98	103.93 ± 10.55$^{b(BCD)}$ (n = 26)	102.55±10.41$^{b(ABCD)}$ (n = 26)	14.85 ± 0.74$^{ab(AB)}$ (n = 24)
	6	313.38 ± 16.80$^{a(A)}$ (n = 36)	302.94 ± 16.24$^{a(A)}$ (n = 36)	0.96	93.41 ± 8.41$^{b(BCDE)}$ (n = 36)	90.29 ± 8.13$^{b(BCDEF)}$ (n = 36)	15.94 ± 0.85$^{a(A)}$ (n = 36)
	8	216.78 ± 13.12$^{b(C)}$ (n = 46)	213.89 ± 12.95$^{b(BC)}$ (n = 46)	0.98	102.87 ± 8.17$^{b(BCD)}$ (n = 46)	101.50 ± 8.06$^{b(BCDE)}$ (n = 46)	12.58 ± 0.76$^{bc(ABCD)}$ (n = 46)
40	0	137.82 ± 9.17$^{b(D)}$ (n = 47)	132.32 ± 9.22$^{b(DE)}$ (n = 48)	0.98	73.80 ± 6.31$^{ab(DEF)}$ (n = 48)	72.33 ± 6.18$^{ab(DEFG)}$ (n = 48)	10.38 ± 0.69$^{b(CD)}$ (n = 47)
	2	215.38 ± 10.37$^{a(C)}$ (n = 43)	203.89 ± 9.82$^{a(BCD)}$ (n = 44)	0.94	79.86 ± 7.40$^{a(CDEF)}$ (n = 46)	75.60 ± 7.01$^{a(CDEFG)}$ (n = 46)	11.99 ± 0.57$^{ab(BCD)}$ (n = 44)
	4	214.04 ± 16.30$^{a(C)}$ (n = 20)	191.20 ± 14.57$^{a(CDE)}$ (n = 19)	0.89	50.43 ± 5.93$^{b(F)}$ (n = 22)	45.05 ± 29.5$^{b(G)}$ (n = 22)	12.74 ± 0.97$^{ab(ABCD)}$ (n = 19)
	6	231.61 ± 15.28$^{a(CB)}$ (n = 29)	190.94 ± 13.04$^{a(CDE)}$ (n = 30)	0.94	73.63 ± 5.42$^{ab(CDEF)}$ (n = 30)	62.39 ± 4.57$^{ab(DEFG)}$ (n = 30)	14.82 ± 0.97$^{a(AB)}$ (n = 30)
	8	240.47 ± 12.64$^{a(ABC)}$ (n = 26)	239.12 ± 16.11$^{a(ABC)}$ (n = 25)	0.90	79.05 ± 8.24$^{ab(DEF)}$ (n = 26)	71.31 ± 7.33$^{ab(DEFG)}$ (n = 26)	13.70 ± 1.01$^{ab(ABC)}$ (n = 26)

The means followed by the same small letters in each row and capital letters in each column are not significantly different ($P < 0.05$, Tukey's test).
n = number of sample.

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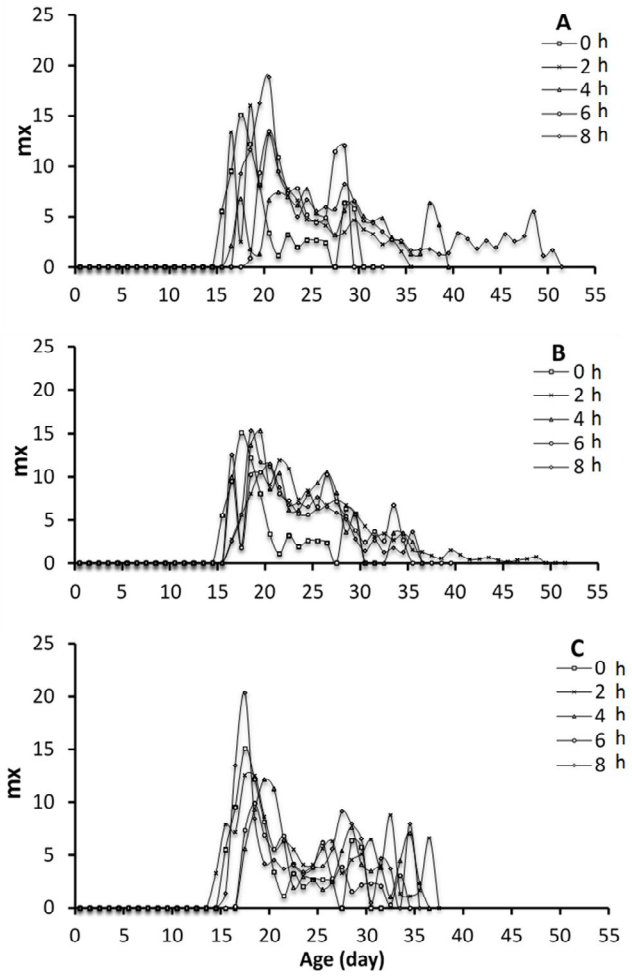

Figure 3 Fecundity rate (m_x) of *Plutella xylostella after* exposure to short- term high temperature stress A (30 °C), B (35 °C) and C (40 °C).

Population growth parameters

The population growth parameters of *P. xylostella* at short-term high temperature stresses in laboratory conditions are shown in Table 2. There was significant difference among the net reproductive rate (R_0) at 30 °C ($F = 16.33$, $df = 4, 205$, $P < 0.05$), 35 °C ($F = 6.49$, $df = 4, 207$, $P < 0.05$) and 40 °C ($F = 4.07$, $df = 4, 173$, $P < 0.05$). The highest and lowest of R_0 (net reproductive rate) were observed at 30 °C for 8 (71.36 ± 4.97 female/ female/ generation) and 2 h (22.64 ± 3.55 female/ female/ generation), respectively.

The intrinsic rate of increase (r_m) was significantly different at stress temperatures, 30 °C ($F = 15.15$, $df = 4,205$, $P < 0.05$), 35 °C ($F = 5.88$, $df = 4,207$, $P < 0.05$) and 40 °C ($F = 11.75$, $df = 4, 173$, $P < 0.05$). The r_m-value ranged from 0.15 ± 0.009 female/ female/ day (30 °C for 4 h) to 0.22 ± 0.004 female/ female/ day (35 °C for 8 h) female/ female/ day.

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Table 2 The population growth parameters of *Plutella xylostella* in short-term high temperatures stress.

Temp (°C)	Exposure time (h)	Doubling time (*DT*)	Finite rate of increase (λ)	Intrinsic rate of increase (r_m)	Generation time (*T*)	Net reproduction rate (R_0)
30	0	$2.92 \pm 0.08^{c(E)}$ (n = 51)	$1.26 \pm 0.008^{a(A)}$ (n = 51)	$0.23 \pm 0.007^{a(A)}$ (n = 51)	$15.56 \pm 0.26^{c(E)}$ (n = 51)	$39.56 \pm 3.36^{bc(CDE)}$ (n = 51)
	2	$3.29 \pm 0.06^{bc(CDE)}$ (n = 51)	$1.23 \pm 0.005^{ab(ABC)}$ (n = 51)	$0.21 \pm 0.004^{ab(ABC)}$ (n = 51)	$18.11 \pm 0.24^{b(ABCD)}$ (n = 51)	$45.03 \pm 3.34^{b(BCD)}$ (n = 51)
	4	$4.58 \pm 0.15^{a(A)}$ (n = 25)	$1.17 \pm 0.01^{c(E)}$ (n = 25)	$0.15 \pm 0.009^{c(E)}$ (n = 25)	$19.83 \pm 0.48^{a(A)}$ (n = 25)	$22.64 \pm 3.55^{c(E)}$ (n = 25)
	6	$3.45 \pm 0.11^{b(CD)}$ (n = 30)	$1.22 \pm 0.008^{b(BCD)}$ (n = 30)	$0.20 \pm 0.006^{b(BCD)}$ (n = 30)	$18.60 \pm 0.27^{ab(ABC)}$ (n = 30)	$44.18 \pm 5.33^{b(CDE)}$ (n = 30)
	8	$3.16 \pm 0.09^{bc(DE)}$ (n = 53)	$1.24 \pm 0.007^{ab(AB)}$ (n = 53)	$0.21 \pm 0.006^{ab(AB)}$ (n = 53)	$19.48 \pm 0.55^{ab(AB)}$ (n = 53)	$71.36 \pm 4.97^{a(A)}$ (n = 53)
35	0	$2.92 \pm 0.08^{b(E)}$ (n = 51)	$1.26 \pm 0.008^{a(A)}$ (n = 51)	$0.23 \pm 0.007^{a(A)}$ (n = 51)	$15.56 \pm 0.26^{c(E)}$ (n = 51)	$39.56 \pm 3.36^{b(CDE)}$ (n = 51)
	2	$3.32 \pm 0.06^{a(CDE)}$ (n = 48)	$1.23 \pm 0.005^{b(ABC)}$ (n = 48)	$0.20 \pm 0.004^{b(ABC)}$ (n = 48)	$20.009 \pm 0.34^{a(A)}$ (n = 48)	$64.91 \pm 4.32^{a(AB)}$ (n = 48)
	4	$3.30 \pm 0.08^{a(CDE)}$ (n = 27)	$1.23 \pm 0.006^{b(ABC)}$ (n = 27)	$0.20 \pm 0.005^{b(ABC)}$ (n = 27)	$18.15 \pm 0.22^{b(ABCD)}$ (n = 27)	$44.66 \pm 4.07^{b(BCD)}$ (n = 27)
	6	3.36 ± 0.09 (n = 39)	$1.22 \pm 0.006^{b(BC)}$ (n = 39)	$0.20 \pm 0.005^{b(BC)}$ (n = 39)	$18.75 \pm 0.41^{b(ABC)}$ (n = 39)	$47.35 \pm 4.20^{b(BC)}$ (n = 39)
	8	$3.09 \pm 0.05^{ab(DE)}$ (n = 47)	$1.25 \pm 0.005^{ab(AB)}$ (n = 47)	$0.22 \pm 0.004^{ab(AB)}$ (n = 47)	$17.81 \pm 0.21^{b(BCD)}$ (n = 47)	$53.71 \pm 3.92^{b(ABC)}$ (n = 47)
40	0	$2.92 \pm 0.08^{b(E)}$ (n = 51)	$1.26 \pm 0.008^{a(A)}$ (n = 51)	$0.23 \pm 0.007^{a(A)}$ (n = 51)	$15.56 \pm 0.26^{c(E)}$ (n = 51)	$39.56 \pm 3.36^{a(CDE)}$ (n = 51)
	2	$3.16 \pm 0.09^{b(DE)}$ (n = 48)	$1.24 \pm 0.008^{a(AB)}$ (n = 48)	$0.21 \pm 0.006^{a(AB)}$ (n = 48)	$16.86 \pm 0.54^{abc(CD)}$ (n = 48)	$39.87 \pm 3.65^{a(CDE)}$ (n = 48)
	4	$4.02 \pm 0.14^{a(AB)}$ (n = 22)	$1.18 \pm 0.007^{b(DE)}$ (n = 22)	$0.17 \pm 0.006^{b(DE)}$ (n = 22)	$18.32 \pm 0.49^{a(ABC)}$ (n = 22)	$23.30 \pm 2.61^{b(E)}$ (n = 22)
	6	$3.69 \pm 0.13^{a(BC)}$ (n = 29)	$1.20 \pm 0.008^{b(CDE)}$ (n = 29)	$0.18 \pm 0.006^{b(CDE)}$ (n = 29)	$17.56 \pm 0.38^{ab(BCE)}$ (n = 29)	$26.88 \pm 2.10^{ab(DE)}$ (n = 29)
	8	$3.17 \pm 0.09^{b(DE)}$ (n = 28)	$1.24 \pm 0.008^{a(AB)}$ (n = 28)	$0.21 \pm 0.006^{a(AB)}$ (n = 28)	$16.15 \pm 0.45^{bc(ED)}$ (n = 28)	33.88 ± 3.64 (n = 28)

The means followed by the same small letters in each row and capital letters in each column are not significantly different ($P < 0.05$, Tukey's test).
n = number of sample

The highest value of finite rate of increase (λ) was obtained at 35 °C for 8 h (0.22 ± 0.004 female/ female/ day), also short-term high temperature stress significantly affected the finite rate of increase at 30 °C ($F = 14.67$, df = 4, 205, $P < 0.05$), 35 °C ($F = 5.85$, df = 4, 207, $P < 0.05$) and 40 °C ($F = 11.42$, df = 4,173, $P < 0.05$). Doubling time (*DT*) was significantly changed with stress temperature ($P < 0.05$),where shortest time *DT* was determined at 30 °C for 8 (3.16 d),

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35 °C for 8 h (3.09 d) and 40 °C for 2 h (3.16 d), respectively. This parameter was significantly different among three short-terms at 30, 35 and 40 °C (Table 2). The generation time (*T*) also significantly differed at 30 °C ($F = 19.02$, $df = 4$, 205, $P < 0.05$), 35 °C ($F = 32.03$, $df = 4$, 207, $P < 0.05$) and 40 °C ($F = 5.35$, $df = 4$, 173, $P < 0.05$), and showed longer generation time at 35 °C for 2 h (20.009 ± 0.34 d) than the others (Table 2).

Discussion

Because extremely high temperatures have a complex impact on insect species, its fitness is probably affected even if it could survive exposure to heat stress (Rinehart *et al.,* 2000; Cui *et al.,* 2008; Zhao *et al.,* 2009). For example, adult survival rates of both *Bemisia tabaci* (Gennadius) biotype B and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) decreased significantly when they were exposed to 41 °C or higher for *B. tabaci*, or 39 °C or higher for *T. vaporariorum* (Cui *et al.,* 2008). The longevity and fecundity of *A. hygrophila* adults decreased significantly with increasing temperature (Zhao *et al.,* 2009). Our results showed that an increase in duration of exposure to the examined high temperature stress resulted in fluctuations in the survival rate of *P. xylostella*. In addition, the fecundity rate of adult *P. xylostella* also significantly fluctuated by increasing short-term high temperature stress. This study indicated that the highest fecundity rate was at 30 °C for 8 h and 35 to 40 °C for 6 h. Post-stress surviving *P. xylostella* also exhibited different responses in fecundity.

After short-term stress, the number of eggs deposited by adult *P. xylostella* differed significantly at the three temperatures, whereas the number of eggs laid by *P. xylostella* decreased at 40 °C. These results indicated that the exposure of *P. xylostella* eggs to short-term temperatures stress ranging from 30 to 40 °C had a significant effect on net fecundity rate. Cui *et al.,* (2008) found that the high temperatures significantly reduced the number of eggs laid by female *T. vaporariorum*, which laid only a few eggs after heat-shock at 43 °C, while no nymphs were hatched at this temperature. In many insect species, high temperatures disrupt the normal functioning of the reproductive system in both sexes (Arbogast, 1981; Mahroof *et al.,* 2005; Cui *et al.,* 2008).

The intrinsic rate of increase (r_m) adequately summarizes the physiological qualities of a species in relation to its capacity to increase (Andrewartha and Birch, 1954). According to our data, all stresses showed a significant effect on life table parameters of *P. xylostella*, especially r_m. the lowest intrinsic rates of increase was obtained at 30 °C for 4 h that resulted in longer generation time, lower survivorship and lower fecundity rate. The r_m values ranged from 0.15 ± 0.009 to 0.22 ± 0.004 female/ female/ d. Golizadeh *et al.,* (2009) investigated the effect of temperature on the life table parameters of *P. xylostella* on cauliflower and cabbage and the r_m values were 0.305 and 0.330 on cabbage and cauliflower at 30 °C and also, were 0.315 and 0.340 on mentioned crops at 28 °C. Also, they reported that the generation time was 13.98 and 14.13 d on cabbage and cauliflower at 30 °C and also was 15.20 and 15.11 d at 28 °C on cabbage and cauliflower, respectively.

It has been reported that heat shock can cause injury to oocytes and ovarian development in females, which can lead to a decrease in egg production. Heat shock can reduce male fertility due to direct injury to the testes and sperm (Chihrane and Lauge, 1997; Krebs and Loeschcke 1994; Rinehart *et al.,* 2000). Geng *et al.* (2005) found that when the middle and late pupal stages of *Trichogramma dendrolimi* Matsumura (Hymenoptera: Trichogrammatidae) was heat-shocked for 6 hours at 35 and 40 °C, emergence rate and the number of wasps per host egg were significantly reduced and nearly all pupae failed to develop into adults. However, they also found that heat shock during the pupal stage had little effect on progeny.

The effect of short-term high temperature stress on the sex ratio of *P. xylostella* was also

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different. It has been reported that changes in sex ratios may affect the population dynamics of the insect (Horiwitz and Gerling, 1992). The results of the present study imply that the development, fecundity and population expansion of *P. xylostella* may be significantly affected when experiencing high temperature summer d in areas invaded by diamondback moths in Tehran. Our findings showed that the fitness of *P. xylostella* significantly increased with increasing temperature from 30 to 35 °C, but the fitness significantly decreased at 40 °C. There may be two modes of killing by heat stress: one mode 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).

In general, the physiological metabolisms of insects vary significantly when they are heat-shocked at extremely high temperatures in order to defend themselves against and avoid high temperature injury (Denlinger and Hallman, 1998; Musolin, 2007; Bale *et al.,* 2002). Previous studies have suggested that the heat shock protein 70 (hsp70) family appears to be the most prominent contributor to thermotolerance in insects (Denlinger and Hallman, 1998), since hsp70 is the protein that responds most dramatically to heat shock (Velazquez *et al.,* 1983). In addition, classic cryoprotectants such as glycerol (Henle and Warters, 1982), glycogen (Denlinger and Hallman, 1998), sorbitol (Wolfe *et al.,* 1998; Salvucci *et al.,* 2000) and lipids (Denlinger and Hallman, 1998) have been reported to protect cultured cells against high temperature stress. Thus, the physiological mechanism of thermotolerance of insects can be revealed by the synthesis of heat shock proteins and the accumulation of classic cryoprotectants in insects.

We only observed that the growth of population, reproductive parameters and biological indices of *P. xylostella* were impacted after short-term high temperature stress in this study. However, the physiological responses of *P. xylostella* to short-term high temperature stress have yet to be explored. Extremely short-term high temperature stress can cause thermal injury due to a sudden increase in temperature (Denlinger and Hallman, 1998). However, this form of injury can be dramatically reduced when the organism is first pre-treated at an intermediately high temperature prior to exposure to extremely high temperatures (Mitchell *et al.,* 1979), which is often referred to as heat acclimation. Increased thermotolerance of insects is often attained by long-term acclimation or rapid heat hardening (Denlinger and Hallman, 1998).

In conclusion, the present study investigated the effects of short-term high temperature stress and exposure patterns on the demographic parameters of *P. xylostella* and can be used to develop a more profound understanding on the potential for *P. xylostella* to evolve in response to environmental changes. According to our data *P. xylostella* can develop and reproduce in a broad temperature range (30-40 °C) and that temperature significantly affects its biological characteristics. Finally, the present study has provided fundamental information for developing new models to simulate and predict population dynamics that will be useful tools for the establishment of optimal control strategies.

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اثر تنش‌های دمایی بالا کوتاه‌مدت روی فراسنجه‌های دموگرافیک بید کلم *Plutella xylostella* (Lepidoptera: Plutelidae)

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چکیده: موجودات اغلب در معرض استرس‌های مختلفی از جمله دما قرار می‌گیرند. بید کلم، *Plutella xylostella* (L.) (Lepidoptera: Plutelidae) مخرب‌ترین آفت گیاهان تیره شب‌بویان یا کلمیان در سرتاسر دنیا است. اثر تنش‌های دمایی بالا کوتاه‌مدت روی تخم و فراسنجه‌های دموگرافیک بید کلم در شرایط آزمایشگاهی مورد مطالعه قرار گرفت. تخم‌های بید کلم در معرض دماهای ۳۰، ۳۵ و ۴۰ درجه سلسیوس به‌مدت ۲، ۴، ۶ و ۸ ساعت قرار گرفتند و سپس به دمای ۲۵ درجه سلسیوس منتقل شدند. نتایج نشان داد که تخم‌های بید کلم تحت تنش‌های دمایی بالا با موفقیت رشد و نمو کرده و به مرحله حشره کامل می‌رسند. طول دوره تخم‌ریزی به‌طور معنی‌داری در دمای ۳۰ درجه سلسیوس به‌مدت ۸ ساعت، ۳۵ درجه سلسیوس به‌مدت ۲ ساعت و ۴۰ درجه سلسیوس به‌مدت ۴ ساعت نسبت به سایر تنش‌هایی دمایی طولانی‌تر بود. تفاوت معنی‌داری بین نرخ خالص تولیدمثل در تنش‌های دمایی بالا کوتاه‌مدت مشاهده شد. بیش‌ترین و کم‌ترین نرخ خالص تولیدمثل به‌ترتیب در ۳۰ درجه سلسیوس به‌مدت ۸ ساعت و ۴ ساعت به‌دست آمد. هم‌چنین نرخ ذاتی افزایش جمعیت در تنش‌های دمایی، تفاوت معنی‌داری داشت. مقدار r_m از ۰/۰۰۹ ± ۰/۱۵ (۳۰ درجه سلسیوس به‌مدت ۴ ساعت) تا ۰/۰۰۴ ± ۰/۲۲ (۳۵ درجه سلسیوس به‌مدت ۸ ساعت) بود. اثر دما روی فراسنجه‌های دموگرافیک بید کلم می‌تواند برای پیش‌بینی دینامیسم جمعیت آفت اقتصادی گیاهان تیره شب‌بویان، کاهش قابل توجه مصرف آفت‌کش‌ها و اثرات سوء آنها بر محیط‌زیست و صرفه‌جویی میلیاردها تومان در سال مورد استفاده قرار بگیرد.

واژگان کلیدی: بیدکلم، دموگرافیک، کروسیفره، نوسانات جمعیت، استرس دمایی بالا کوتاه‌مدت

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