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Effects of Temperature on the Development of *Ephestia cautella* (Walker) (Pyralidae: Lepidoptera): A Case Study for its Possible Control Under Storage Conditions

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Abstract.- *Ephestia cautella* (Walker) is a serious pest of dates both in the field and under storage conditions. The control of stored product pests and especially those of food products by manipulating temperature would be the best and safe choice. In this study, we examined the effects of temperature on developmental traits of *E. cautella* under laboratory conditions. For this study, newly hatched *E. cautella* larvae were reared at 25°C and 35°C, with 65 ± 5% relative humidity and a photoperiod of 15:9 (L:D). Biological parameters studied were: number and duration of larval instars; survival rate of larvae, pupae, and adults; total life span; and fecundity and fertility. Temperature had a significant impact on *E. cautella* development. At 5°C, there was 100% mortality; eggs failed to hatch, and no larval or pupal survival was observed. On the other hand, *E. cautella* pupated after five larval instars at 25°C while six instars were observed at 35°C. The larval period significantly increased at 35°C. However, total lifespan of both sexes was considerably longer at 25°C. Of the three temperatures studied, 25°C was highly favorable for fecundity, egg hatchability, and overall survival of all life stages. Complete mortality at 5°C indicated that storage at lower temperatures can prevent the storage losses inflicted by *E. cautella*.

Key Words: *Ephestia cautella*, developmental traits, temperature, dates storage.

INTRODUCTION

Saudi Arabia leads the world in date palm (*Phoenix dactylifera* L.) production; the country grows more than 400 different date palm cultivars, with an annual date production of 700,000 tons (Alabdulhadi *et al.*, 2004). According to the FAO (Food and Agriculture Organization of the United Nations) report, Saudi dates production was second third in 2011 (FAOSTAT, 2011). Date palm tree and its fruit are vulnerable to several insect pests, both in the field and in storage. *Ephestia cautella* moths are serious pests of dried plant materials and have been recorded from cereal grains and their products, dried fruit, nuts, oilseeds, pulses, and cacao (Richards and Thomson, 1932; Arbogast *et al*., 2005).

E. cautella causes substantial damage to dates held in storage (Al-Zadjali *et al.*, 2006), with an average infestation rate of 16.8% (Al-Mjeni *et al*., 1983). However, the fruit losses may reach to 100% if appropriate control measures are not applied.

Under ordinary storage conditions, 4-5 overlapping generations of *Ephestia cautella* have been observed each year and, the duration of each generation depends on the season (Hussain and Khaiyoon, 1966; Kamel *et al*., 1976). The longevity of all developmental stages is highly subjective to the temperature, relative humidity, and availability of food (Subramanyam and Hagstrum, 1993). In *E. cautella*, a negative correlation exists between the eggs incubation period and temperature and relative humidity (Shoukry *et al.*, 1978). Reproduction of *Plodia interpunctella*, another pyralid moth, was optimized at 25-30ºC, with an oviposition period of 18 days or less (Arbogast, 2007), and also its fecundity and sex-ratio was determined (Hamed *et al*., 2010).

Previous reports provided information on effects of photoperiod and temperature on *E. cautella* diapause (Bell and Bowley, 1980), effect of diet quality on its fecundity and longevity (Al-Taweel *et al.*, 1995), and oviposition behavior and reproduction (Lum, 1977; Olsson and Anderbrant, 2005). Information on developmental traits of this pest as affected by temperature and relative

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humidity, especially under Saudi storage conditions, is not available.

The objective of this study was to determine the effects of temperatures on developmental traits of *E. cautella*. This information will be useful in devising an effective and efficient strategy for *E. cautella* population management that will help to minimize the losses of dates in date storage warehouse.

MATERIALS AND METHODS

E. cautella adults were obtained from a mass culture maintained at Economic Entomology Research Unit (EERU) laboratory. Newly emerged adults of *E. cautella* were collected and 50 male-female pairs were transferred to plastic containers (77 mm diameter, 146 mm deep, one container per pair) containing cotton swabs soaked with 10% sugar solution (Shoukry, 1978). The mouth of the container was wrapped with a plastic mesh (Bell and Bowley, 1980) using a rubber band and inverted on a loosely affixed lid. Eggs laid were collected daily from the lid and individually transferred to rearing cups (65 mm diameter, 32 mm deep) using a No. 0 brush. Each cup was provided with 20 mg of artificial diet (each kilogram of diet contained 375 g broiler diet, 375 g layer diet, and 250 g wheat flour) in 100 ml glycerin and kept at 25ºC with 65 ± 5% relative humidity (RH), and a photoperiod of 15:9 h (L:D) in an incubator until hatching.

Initially, 1,000 eggs were incubated for hatching and observed daily. Developmental traits of *E. cautella* were investigated at three temperatures: 5, 25 and 35ºC. Eggs hatching on the same day (at 25ºC) were divided into three groups (for 5°C, 25°C and for 35ºC), each with four replicates and each containing 40 neonate larvae. Larvae of each group were transferred to their respective temperatures in incubators fixed at 65±5% RH and a photoperiod of 15:9 h (L:D). Since the first-instar larvae could not survive at 5°C larvae of each instar were exposed to 5ºC (after having been reared at 25°C). Larval development was observed in terms of (a) duration of each larval instar (in days) and (b) the total number of larval instars. Also, sex ratio was determined on day 3 of the fifth instar larvae based on the presence or absence of dark testes (Boles and Marzke, 1966). The diet was changed at each molting and 20, 30, 40, 60, and 75 mg diet was provided to 1st to 6th instar larvae, respectively.

Survival rates of larvae, developmental period and survival rates of pupae were also calculated. Pupae emerged at 25ºC were exposed to 5ºC for 60 days and then transferred back to 25ºC for 90 days to observe the adult emergence.

The newly emerged adults (both male and female) were transferred to plastic containers in pairs as described above for fecundity analysis. Pairs were kept in these containers for their entire adult lives. The number of eggs laid each day and the total number of eggs laid by each female during her life span were recorded. Eggs laid each day were transferred to the petri dishes lined with moist filter paper, and kept at 25ºC to observe the hatching percentage. Pre-oviposition, oviposition, and post-oviposition periods were also recorded. Number of emerging males and females was recorded to determine the sex ratio.

Data were analyzed using the analysis of variance (ANOVA) PROC GLM procedure in SAS (SAS, 2009), and means were separated using least significant difference (LSD) ($P = 0.05$). It is to be noted that comparisons were made only between the data originated from 25 and 35ºC as values obtained at 5ºC were all zero.

RESULTS

Larval development

Temperature had a significant effect on the larval development of *E. cautella* (Fig. 1). No larvae of *E. cautella* could survive at 5°C. In all cases, larval activity was ceased within a few hours of exposure to 5°C. Larvae were exposed to 5°C for 60 days, their bodies shriveled and changed to grayish in color; no signs of life were observed. Larval development at 25°C were significantly longer than those at 35°C ($F = 4.22$, df = 1,174, $P = 0.04$; $F = 24.05$, df = 1,174, $P < 0.0001$; $F = 20.94$, df = 1,174, $P < 0.0001$; $F = 40.20$, df = 1,174, $P < 0.0001$; and $F = 149.82$, df = 1,174, $P < 0.0001$ for first through fifth instar, respectively). *E. cautella* larvae passed through five instars at 25°C and six instars at 35°C. Total larval duration was significantly longer (Fig.

2) at 35°C (F = 45.07, df = 1,174, P < 0.0001) than at 25°C.

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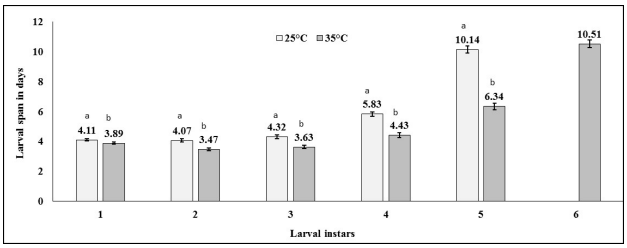

Fig. 1. Effect of temperature on average duration of each larval instar of *Ephestia cautella.* Larvae underwent five instars at 25°C and six at 35°C. Within each instar, columns with different letters above are significantly different (P<0.05).

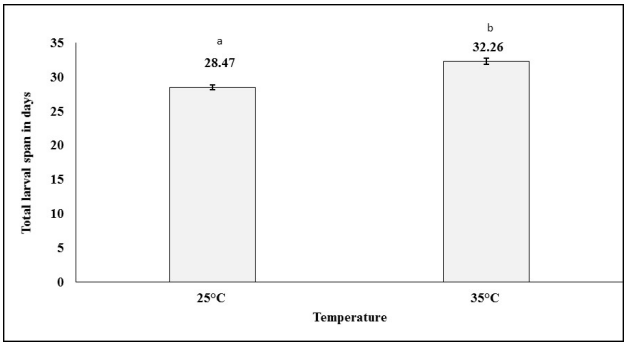

Fig. 2. Effect of temperature on average larval duration of *Ephestia cautella.* Columns with different letters are significantly different (P<0.05).

Pupal development

Pupal development was significantly affected by the temperature, the developmental differences were observed even in the gender (males and females) and at the same temperature (Fig. 3). However, the pupae (emerged from larvae reared at 25°C) when exposed to 5°C for 60 days were not able to emerge as adults, and same was observed when they were transferred back to 25°C for 90 days. Pupae at 25°C took significantly longer to emerge as adults (females: F = 7.40, df = 1, 74, P = 0.008; males: F = 80.36, df = 1, 75 P < 0.0001) as compared to the those reared at 35°C.

Adult longevity

Longevity of adult *E. cautella* was significantly affected by the temperature (Fig. 4). The difference in adult's longevity was observed under different temperatures. A significantly higher longevity was observed in both males and females at 25°C as compared to 35°C (females: F = 35.57, df = 1, 64, P < 0.0001; males: F = 58.88, df = 1, 60, P < 0.0001). However no gender-specific difference in longevity was detected at the same temperature (25°C: F = 1.43, df = 1, 69, P = 0.24; 35°C: F = 1.37, df = 1, 55, P = 0.25).

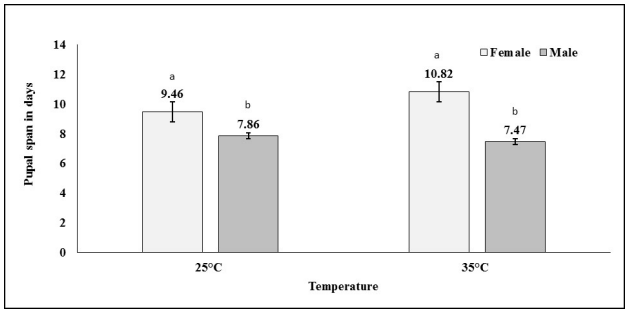

Fig. 3. Effect of temperature on pupal duration in *Ephestia cautella.* For each temperature, columns with different letters are significantly different (P<0.05).

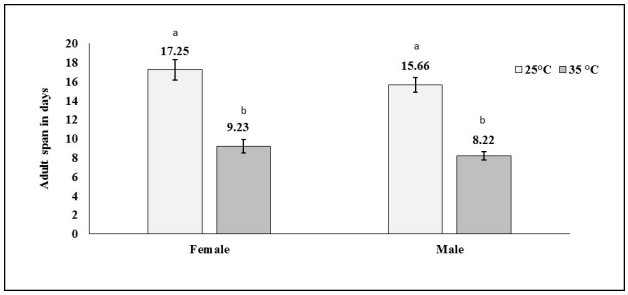

Fig. 4. Effect of temperature on average adult life span of *Ephestia cautella.* In each category, columns with different letters are significantly different (P<0.05)

Total lifespan

At 25°C, *E. cautella* lived significantly longer (F = 28.62, df = 1,123, P < 0.0001) as compared to 35°C. A similar trend was observed when lifespans for females and males were calculated separately (females: F = 12.04, df = 1, 52, P = 0.0011; males: F = 19.55, df = 1, 76, P < 0.0001). No significant difference (25°C: F = 0.48, df = 1, 67, P = 0.49; 35°C: F = 0.00, df = 1, 61, P=0.97) was detected

between female and male life spans within each temperature treatment (Fig. 5).

Fecundity and fertility

Temperature also had a significant effect on female fecundity and fertility of *E. cautella* (Fig. 6). Both fecundity and fertility were significantly higher (fecundity: F = 103.81, df = 1, 40, P < 0.0001; fertility: F = 13.30, df = 1, 40, P = 0.0008) at 25°C than at 35°C.

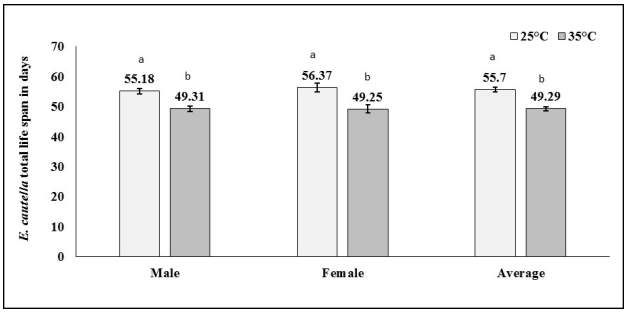

Fig. 5. Effect of temperature on average life span of *Ephestia cautella.* In each category, columns with different letters are significantly different (P<0.05).

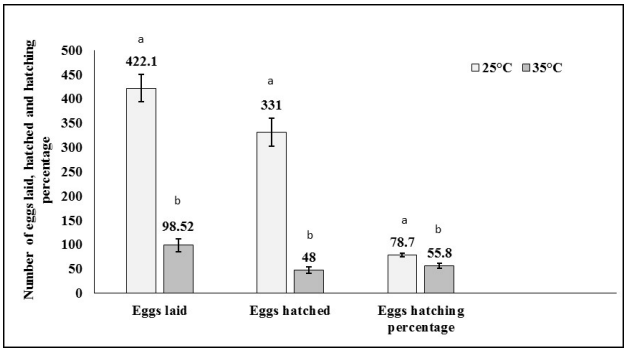

Fig. 6. Effect of temperature on average fecundity and fertility of *Ephestia cautella.* At each category, columns with different letters are significantly different (P<0.05).

Oviposition period

There were no significant differences observed between pre-oviposition (F = 0.12, df = 1, 16, P = 0.73) and post-oviposition periods (F = 1.21, df = 1, 16, P = 0.29) at both 25°C and 35°C (Fig. 7). However, females at 25°C laid eggs for significantly longer periods (oviposition period: F = 6.44, df = 1, 16, P = 0.02) as compared to females at 35°C.

Egg incubation period

Eggs hatching was observed on day 2 after being laid at both 25°C and 35°C that continued until day 7 (at 25°C) (Fig. 8). At 25°C, egg hatching was significantly much higher on day 4 (F = 42.77, df = 5, 48, P <0.0001), whereas at 35°C, egg hatching was significantly more on day 3 (F = 19.36, df = 4, 40 P <0.0001).

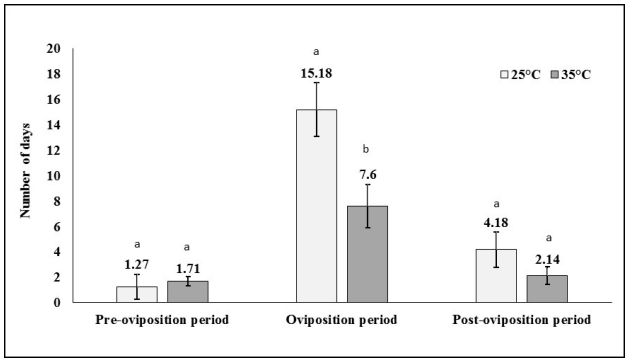

Fig. 7. Effect of temperature on average pre-oviposition, oviposition and post oviposition periods of *Ephestia cautella.* Within each category, columns with different letters are significantly different (P<0.05).

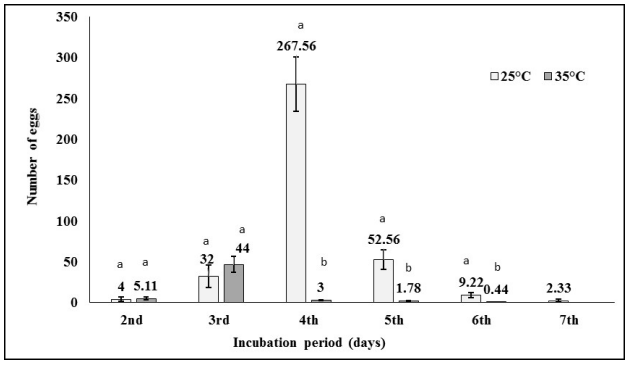

Fig. 8. Effect of temperature on the egg incubation period of *Ephestia cautella*. For each day, columns with different letters are significantly different (P<0.05).

Survival

Survival of the *E. cautella* was also significantly affected by the temperature (Table I). No *E. cautella* could survive at 5°C while a significantly high survival was observed at 25°C (to pupae: F = 10.24, df = 1, 6, P = 0.02; to adults: F =

6.78, df = 1, 6, P = 0.04) as compared to that of 35°C.

Table I.- Effect of temperature on survival of *Ephestia cautella.*

Temperatures	Survival of *Ephestia cautella* at different temperatures		
	Larvae introduced	Larvae pupated	Adults emerged
25°C	40	29.75±1.50a	27.25±1.75a
35°C	40	24.00±1.00b	19.75±2.29b

Means within a column followed by the same letter are not significantly different $\alpha = 0.05$

Table II.- Male to female ratio of *Ephestia cautella* reared at different temperatures.

Temperature	Males	Females
25°C	0.55	0.45
35°C	0.49	0.51

Sex ratio

The sex ratio was determined for *E. cautella* reared at both 25°C and 35°C. Male: female ratio was 0.55:0.45 and 0.49:0.51 at 25°C and 35°C, respectively (Table II).

DISCUSSION

Ephestia cautella is a major pest of stored food products including dates, a highly valued annual fruit which is stored after harvesting for processing and marketing. The control of stored product pests and especially those of food products by manipulating temperature would be the best and safe choice. Our results indicated that *E. cautella* is greatly influenced by temperature, as previously shown by other scientists (Shoukry *et al.*, 1978; Subramanyam and Hagstrum, 1993).

There was no development or survival observed at 5°C of any larval instar or pupal stage. Larvae and pupae exposed to 5°C for 60 days were transferred to 25°C for 90 days but could not recover, demonstrating that they were not in cold-induced diapause. Burges (1956) also exposed half-grown *E. cautella* larvae to 0°C for five days and to 5°C for 32 days, and all failed to develop into pupae. Since the developmental threshold temperatures for Lepidoptera are reported to be >13°C (Ali *et al.*, 1990), storing dates below threshold temperatures should be safe.

Of the temperatures studied, 25°C was the best suited temperature for *E. cautella* rapid larval growth, survival, fecundity, and fertility. A higher temperature, 35°C, was less conducive to *E. cautella* development. Tuli *et al.* (1966) also recorded a considerable reduction in the fecundity of *E. cautella* reared at 35°C. Bell (1975) found that *E. elutella* (Hűbner) and *E. kuehniella* (Zeller) were unable to reproduce when reared at 30°C. Lum (1977) reported that eupyrene sperm development was inhibited, resulting in low fecundity, in *Plodia interpunctella* (Hűbner) when pupae and pre-pupae were exposed to 35°C for about three days. Johnson *et al.* (1992) reported that no progeny resulted from adults reared at 35°C, regardless of diet. In the present study, 35°C prolonged the larval developmental time with addition of an instar and reduced the survival rate, fecundity, and fertility. Kamel *et al.* (1976) found 6-8 larval instars in *E. cautella* at an average temperature of 32.1°C, whereas more than 60% of the larvae had six instars.

The findings of the present study conclusively demonstrated that (1) temperature had a significant effect on development of *E. cautella*; (2) exposure to 5°C resulted in total mortality of all development stages of *E. cautella* (3) 25°C was an optimum temperature for *E. cautella* development while 35°C was less favorable. Fields (1992) has reported three temperature zones for any organism: optimum (25-33°C), where the species' fitness is the highest in terms of development and number of offspring; suboptimum (13-25°C), where temperature is below the optimum zone but where species can still complete their life cycle; lethal (5°C and below), where temperature is below the suboptimum zone and kill the organism over time. Thus our results unequivocally suggest that use of low temperatures (5°C) can be the best technique for the control *E. cautella* during prolonged date storage. Low temperature is probably the most significant solitary element in making long term storage possible and economical.

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