Effect of temperature on development and reproductive characteristics of *Diaphania indica* (Saunders) (Lepidoptera: Pyralidae)

Kinue Kinjo¹ and Norio Arakaki

Okinawa Prefectural Agricultural Experiment Station, Naha, Okinawa 903–0814, Japan

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Abstract

The effect of temperature on the development of the cotton caterpillar, *Diaphania indica* (Saunders) was examined by rearing cohorts on cucumber *Cucumis sativus* L. leaves at various constant temperatures. The developmental periods were 47.4, 24.4, 18.2 and 19.7 d at 20, 25, 30 and 35°C, respectively. The lower threshold temperature and total effective temperature for development of the pre-adult stage were determined to be 13.5°C and 294.1 degree days, respectively. At 25°C, the mean adult longevity of males (21.6 d) was significantly longer than that of females (16.7 d). Pre-oviposition and oviposition periods were 1.04 d and 14.8 d, respectively. The total number of eggs produced per female was 808.7. Pupal weights and total numbers of eggs oviposited were positively correlated. The intrinsic rate of natural increase (r_m) was 0.20 per day.

Key words: *Diaphania indica*, development, fecundity, lower threshold temperature, total effective temperature

INTRODUCTION

The cotton caterpillar, *Diaphania indica* (Saunders) (Lepidoptera: Pyralidae) is a serious pest, particularly of cucurbitaceous crops. It is widely distributed in Japan, Southeast Asia, India, Pacific Islands, Australia, Africa and other areas (Peter and David, 1991). In Okinawa, this species primarily infests the balsam pear *Momordica charantia* L., the wax gourd *Benincasa cerifera* Savi., and the sponge gourd *Luffa aegyptiaca* Mill. in field cultivations, and the cucumber *Cucumis sativus* L., *M. charantia* and the melon *C. melo* L. in greenhouse cultivations. The larvae mainly attack leaves but also infest flowers and fruits, and cause considerable yield loss during outbreaks.

In Japan, little attention has been paid to this important pest of cucurbitaceous crops. Since the early 1990's, however, serious damage on the balsam pear by *D. indica* in greenhouse cultivations was sporadically observed on Okinawa Island (Tokashiki and Yasuda, 1991; Kinjo, unpublished data). Severe damage by this species was also observed on greenhouse cucumbers and melons in Chiba Prefecture, central Honshu in 1998 and 1999 (Shimizu, 2000).

Knowledge of reproductive ability of this

species is important for an understanding of the greenhouse outbreaks and for improvement of crop protection. This paper presents data on the developmental rate for each immature stage of *D. indica* at five different constant temperatures to determine the lower thermal thresholds and total effective temperature. We also examined adult fecundity and longevity at 25°C to estimate reproductive ability.

MATERIALS AND METHODS

Effect of temperature on the development of *D. indica*. Larvae were collected from cucumber leaves at Tomishiro, Okinawa, on July 1998, and then they were reared on cucumber leaves at 25°C under a photoregime of 16L–8D until pupation. Pupae were sexed and kept in separate plastic cups (5 cm dia.×3.5 cm ht.) until emergence. Pairs of virgin females (1-d-old) and males (1- to 3-d-old) were confined in plastic cups (11 cm dia.×10 cm ht.) for mating. Mated females were reared individually in transparent plastic cups (11 cm dia.×10 cm ht.) and provided with a piece of cucumber leaf as an oviposition substrate and diluted honey solution-soaked cotton. Fresh eggs laid on the cucumber leaf were counted and transferred into plastic cups (5 cm dia.×3.5 cm ht.) and kept at five differ-

¹ Present address: Okinawa Prefectural Plant Disease and Insect Control Station, Naha, Okinawa 903–0814, Japan

Table 1. Development of *Diaphania indica* at various temperatures under a photoregime of 16L–8D

Developmental stage	Developmental period (d; mean±SD)				
	15°C	20°C	25°C	30°C	35°C
Egg	19.8±1.8 (83)	8.0±0.1 (76)	4.0±0 (76)	3.0±0 (49)	3.0±0 (50)
Larva 1st	19.0 (1)	4.0±0.6 (74)	2.1±0.3 (76)	1.3±0.5 (49)	1.2±0.4 (45)
2nd		3.3±0.6 (74)	1.9±0.3 (76)	1.7±0.5 (46)	1.7±0.5 (39)
3rd		3.3±0.6 (73)	2.0±0.2 (76)	1.1±0.3 (45)	1.6±0.7 (27)
4th		4.4±0.5 (72)	2.1±0.4 (76)	1.4±0.6 (45)	2.1±0.6 (18)
5th		3.8±0.6 (69)	2.4±0.5 (75)	2.3±0.6 (45)	2.5±0.6 (17)
Prepupa		4.0±0.2 (66)	2.0±0 (73)	1.9±0.3 (45)	1.8±0.4 (13)
1st–Prepupa		22.8±1.0 (66)	12.4±0.5 (73)	9.8±0.7 (45)	11.2±0.7 (13)
Pupa		16.5±0.6 (62)	8.1±0.3 (69)	5.5±0.5 (42)	5.7±0.5 (7)
Egg–Adult		47.4±1.2 (62)	24.4±0.6 (69)	18.2±0.7 (42)	19.7±0.8 (7)

Values in parentheses are numbers of individuals observed.

ent constant temperatures (15, 20, 25, 30 and 35°C) under a photoregime of 16L–8D until eclosion. Newly hatched larvae were individually reared in plastic cups (5 cm dia.×3.5 cm ht.) on a piece of fresh cucumber leaf at five different constant temperatures (15, 20, 25, 30 and 35°C) under the same photoregime. The bottom of each cup was lined with a slightly moistened filter paper to prevent desiccation. Larval development was checked daily. The cup and cucumber leaf were exchanged at 2- or 3-d intervals. Pupae were weighed 2 d after pupation using an electric balance.

Adult longevity and fecundity of *D. indica*.

Larvae were collected from cucumber plants at Chinen, Okinawa on October 1997, and reared on cucumber leaves at 25°C under a photoregime of 16L–8D. Pupae were weighed by an electric balance and kept individually in plastic cups (5 cm dia.×3.5 cm ht.). Pairs of virgin females (1-d-old) and males (1-d-old) were confined together in cups (11 cm dia.×10 cm ht.) for mating. Mated females and males were separated individually into cups and provided with diluted honey solution-soaked cotton. Single pieces of cucumber leaves (1.5 cm ×3 cm) were placed into females' cups as oviposition substrate. Females laid eggs not only on cucumber leaves but also on cup walls and cotton. To count eggs laid, females were transferred daily to new cups with a piece of fresh leaf and honey solution. For the males, honey solution was added to the cotton each day. Cups and cotton were exchanged at 3–4 d intervals.

The net reproductive rate (R_0) was determined

using the following equation (Ito and Murai, 1977):

$$R_0 = \sum l_x m_x$$

where l_x =the proportion of population surviving to age x , and m_x =the number of female offspring per female aged x per day.

The intrinsic rate of increase (r_c) was estimated from the following equation (Ito and Murai, 1977):

$$r_c = \ln R_0 / T$$

where T =mean generation time.

RESULTS AND DISCUSSION

Effect of temperature on the development of *D. indica*

The developmental period for the egg stage decreased with increases of temperature from 15°C to 30°C, but not from 30°C to 35°C (Table 1). The developmental periods for larval and pupal stages decreased with increases of temperature between 20°C and 30°C. However, the developmental period at 35°C was longer than that at 30°C. This is probably a deleterious effect of high temperature on larval and pupal development.

Between 20°C and 30°C, a good correlation was obtained between developmental rate and temperature (Table 2). Lower threshold temperatures for development (developmental zero) of egg, larva, pupa and egg to adult emergence were estimated to be 13.7, 12.0, 14.9 and 13.5°C, respectively. Total effective temperatures for development were 48.1,

Table 2. Thermal requirements for development of *Diaphania indica*^a

Developmental stage	Regression equation	r^2	Lower threshold temperature	Total effective temperature
Egg	$Y=0.021X-0.284$	0.99	13.7	48.1
Larva	$Y=0.006X-0.070$	0.99	12.0	172.4
Pupa	$Y=0.012X-0.181$	1.00	14.9	82.6
Total	$Y=0.003X-0.046$	0.99	13.5	294.1

^a From data for 20, 25 and 30°C.Table 3. Survival of *Diaphania indica* at various temperatures under a photoregime of 16L–8D

Temperature (°C)	Number of eggs	Eclosion		Pupation		Emergence	
		Number	Rate (%)	Number	Rate (%)	Number	Rate (%)
15	115	83	72.2	0	0	0	0
20	76	76	100	66	86.8	62	81.6
25	76	76	100	73	96.1	69	90.8
30	49	49	100	45	91.8	42	85.7
35	50	50	100	13	26.0	7	14.0

172.4, 82.6 and 294.1 degree days, respectively.

The hatchability of the eggs attained 100% at 20–35°C, but was 72.2% at 15°C (Table 3). At 15°C, in the dead eggs, larval body formation was observed through the transparent egg cell to be almost complete. Death of eggs was, therefore, considered to occur at the later developmental stage. Only one larva among 83 first stadium larvae molted to the second stadium, and the rest died during the first stadium. No larvae attained the third stadium. Temperatures as low as 15°C are considered to be lethal to the eggs and young larvae of *D. indica*.

Pupation rates from eggs were 87–96% at 20–30°C, but only 26% at 35°C. Adult emergence rates exceeded 80% at 20–30°C, but were only 14% at 35°C. Reduction of survival is also thought to be a deleterious effect of high temperature. The pupal weights were 82.9, 67.5, 59.1 and 48.7 mg at 20, 25, 30 and 35°C, respectively. Inverse correlation was observed between pupal weight and temperatures ($r^2=0.98$). This indicates that the larvae reared at the higher temperatures grew faster but became smaller within these temperature ranges. Mean pupal weight of females ($N=189$) and males ($N=165$) at 25°C were 68.2 and 67.6 mg, respectively. There was no significant difference between

female and male pupal weights ($p<0.05$, t -test).

The developmental period from egg to adult in the Okinawa population was 18.2 d when reared at 30°C (Table 1). At Tamil Nadu, South India, it was 23.4 d when reared at the same temperature (Peter and David, 1992). In the Okinawa population, a deleterious effect of high temperature on development and survival was observed at 35°C (Tables 1 and 3). In contrast, the developmental period in the South India population was the shortest at 40°C when reared at 25–40°C (Peter and David, 1992). That is, no deleterious effect of high temperature was observed. As there are large climatic differences between Okinawa, Chiba and South India, it is likely that local populations, or strains, have adapted to these conditions. The lower threshold temperature for development and the thermal constant for the pre-adult stage were determined to be 13.5°C and 294.1 degree-days, respectively, in the Okinawa population (Table 2), 12.3°C and 357.0 degree-days, respectively, in the Chiba population of Japan (Shimizu, 2000), and 12.05°C and 454.55 degree-days, respectively, in the South India population (Peter and David, 1992).

Based on the data of the lower threshold temperature for development and total effective temperature for the pre-adult stage in *D. indica*, we esti-

Fig. 1. Survival rate and daily egg production of *Diaphania indica* adults at 25°C under a photoregime of 16L–8D.

mated that nine generations occur in Okinawa per year. Developmental period for the pre-adult stage in this species was the shortest at 30°C, and survival rates in larvae and pupae were the largest at 25°C. Therefore, the most suitable temperature range for development is 25 to 30°C in the Okinawa population. This species might propagate primarily in summer.

Adult longevity and fecundity of *D. indica*

Female survival rate remained at 100% until the 8th day after emergence, then gradually decreased and diminished to zero by the 29th day (Fig. 1). Male survival rate decreased more slowly than that of females, and diminished to zero by the 33rd day. The mean female adult longevity (16.7 d) was significantly shorter than that of the male (21.6 d, $p < 0.01$, t -test).

Females laid most eggs on the cucumber leaf, and a small number on the inside wall of the cup and cotton pad. All mated females started to oviposit on the 2nd day after mating. The maximum mean daily egg production was observed on the 4th day (147.0 eggs/female/d) (Fig. 1). The cumulative number of eggs oviposited up to the 8th day was 692.4, which was 85.6% of the total number of eggs laid. Thus, females laid eggs intensively in the early part of the survival period.

Pre-reproductive and oviposition periods of females were 1.04 ± 0.2 d (mean $\pm$ SD, $N=71$) and 14.8 ± 15.6 d ($N=71$), respectively. The mean total number of eggs produced was 808.7 ± 185.7 /female ($N=71$). Oviposition period and total number of

eggs showed large variations among individuals, which ranged from 5 to 25 d and from 296 to 1,231/female, respectively. In the Chiba population that was reared on an artificial diet, the total number of eggs was 63.4/female (Shimizu, 2000). Thus a great difference was observed in the total number of eggs between the Okinawa and the Chiba populations. However, we could not directly compare the fecundity of the two populations because the Okinawa population was reared on cucumber leaves.

Pupal weight (female) and total number of eggs oviposited were positively correlated ($r^2=0.4$). Similar positive correlations were observed in other Pyralidae, i.e. in the Mexican rice borer, *Eoreuma lofti* (Dyar) (Spurgeon et al., 1995), and the Mediterranean flour moth, *Anagasta kuehnielle* (Zeller) (Daumal and Boinel, 1994). In both species, there were positive correlations between the weight of pupae or the final stadium larvae and the number of oocytes within ovarioles. Although we did not examine the number of oocytes, a similar trend would be expected. Also, females that live longer tend to have higher fecundity.

Basic population parameters including R_0 , r_c , and T were calculated on the basis of the fertility schedules in Fig. 1. The mean generation time (T) of the Okinawa population was 29.5 d and the net reproductive rates (R_0) was 383.5-fold per generation. The intrinsic rate of increase (r_c) was 0.20 per individual per day. Therefore, *D. indica* in Okinawa has a fairly high reproductive ability. Wang (1989) reported that intrinsic rates of the 2nd and 3rd gen-

erations in the China population were 0.0792 and 0.0487 when reared at 28°C and under natural day length. These values were extremely low compared to those obtained from our study. This difference is greatly affected by the extremely lower survival rate in the immature stage in Wang (1989).

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