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Effect of constant temperature on the development of *Sceliodes cordalis* (Doubleday) (Lepidoptera: Crambidae) on eggplant

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Abstract *Sceliodes cordalis*, eggfruit caterpillar, is an important pest of eggplant in Australia but little information was available on its biology. This study was conducted to determine the effect of temperature on the development on eggplant of eggs, larvae and pupae. Insects were reared at five constant temperatures from 20.5°C to 30.5°C with a 12:12 L : D photoperiod and the thermal summation model was fitted to the developmental rate data. Developmental zeroes and thermal constants of 11.22°C and 61.32 day-degrees for eggs, 12.03°C and 179.60 day-degrees for larvae, and 14.43°C and 107.03 day-degrees for pupae were determined. Several larvae reared at 20.5°C entered diapause.

Key words aubergine, eggfruit caterpillar, thermal summation.

INTRODUCTION

Sceliodes cordalis (Doubleday), eggfruit caterpillar, is an important pest of eggplant (*Solanum melongena*) in Australia. Eggplant is the main commercial host of *S. cordalis* but it occasionally attacks tomato (*Lycopersicon esculentum*) and capsicum (*Capsicum annuum*) and it has been recorded from solanaceous weeds such as thornapples (*Datura* spp.) and quena (*Solanum esuriale*) (Davis 1964). In New Zealand *S. cordalis* is a serious pest of pepinos (*Solanum muricatum*) and is common on poroporo (*Solanum aviculare*) (Galbreath & Clearwater 1983). Davis (1964) described the insect and its habits. Eggs are usually laid on the calyx and the neonate larvae tunnel into the fruit. The larvae feed inside the fruit, emerging as mature larvae to pupate nearby in a tough silken cocoon. The internal damage caused by the larval feeding makes the fruit unusable. Fruit with larval exit holes are rejected at harvest, but fruit with larvae still feeding inside may be picked and are only detected when the larvae emerge later or when the fruit are cut. Losses can be high. Brown (2002) found that 10–58% of fruit collected from unsprayed crops in north Queensland were damaged by *S. cordalis*. Kay and Brown (2009) reported up to 26% of fruit damaged in unsprayed control treatments in insecticide trials and damage levels of up to 14% have been recorded in sprayed commercial crops (I Kay unpubl. data 2007).

Studies on *S. cordalis* have been undertaken on its pheromone (Galbreath & Clearwater 1983; Clearwater *et al*. 1986), pathogens (Dhana 1984; Mercer & Wigley 1987a,b,c), insecticidal control (Martin & Workman 1985; Kay & Brown 1992, 2009) and its seasonal occurrence in New Zealand (Martin 1999). However, apart from the estimates of the durations of the egg, larval and pupal stages under the warm conditions of spring and early summer in north Queensland (Davis 1964), the effect of temperature on the development of *S. cordalis* has not been studied despite the critical importance of temperature as a driving factor in insect development and population dynamics (Kitching 1977).

Plotting insect developmental rates (i.e. the reciprocal of developmental times) against temperature results in a shallow sigmoidal curve, the middle section of which approximates a straight line. Many models have been derived to describe the rate of development versus temperature curve. They include the simple linear thermal summation model and various more complex non-linear models, which are briefly reviewed in Allsopp *et al*. (1991), Kontodimas *et al*. (2004) and Walgama and Zalucki (2006). The thermal summation model, using temperatures in the straight line portion of the curve, allows the calculation of the developmental zero, the lower temperature threshold below which there is no development, and the thermal constant, which is the number of day-degrees above the developmental zero required for development.

This study was conducted to determine the effect of a range of constant temperatures on the development time of *S. cordalis* eggs, larvae and pupae.

MATERIALS AND METHODS

Sceliodes cordalis moths were reared from fruit from an unsprayed crop of eggplant at Bundaberg Research Station (24°52′S, 152°21′E) to establish a laboratory colony maintained in a constant temperature room at approximately 24°C with a 12:12 L : D photoperiod. The moths were held in plastic containers (350 mm by 250 mm by 140 mm) with a fine-weave curtain gauze material lid, and were provided with a sugar solution. The females laid eggs on the gauze material and the resulting larvae were provided with fruit in which to

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Table 1 Development times and survival of *Sceliodes cordalis* eggs, larvae and pupae at constant temperatures

Temperature (±0.5°C)	Development time (days)			Percent completing development
	Mean (*n*)†	±SD	Range	
Eggs				
20.5	7.38 (37)	0.32	6.5–8.0	70
23.5	4.97 (43)	0.25	4.0–5.5	83
25.0	4.11 (36)	0.30	4.0–5.5	75
28.0	3.5 (47)	0.0	–	90
30.5	3.41 (38)	0.20	3.0–3.5	88
Larvae				
20.5	22.58 (19)	2.46	18–26	79
23.5	16.08 (26)	2.58	12–21	81
25.0	13.40 (20)	2.11	10–17	83
28.0	11.58 (19)	2.17	9–18	79
30.5	10.91 (21)	1.83	8–14	88
Pupae				
20.5	19.53 (15)	1.73	18–25	100‡
23.5	12.31 (26)	1.12	10–15	100
25.0	9.45 (20)	1.50	6–14	100
28.0	7.68 (19)	0.82	6–9	100
30.5	7.00 (21)	0.55	6–8	100

†Number of individuals. ‡Excluding the four that entered diapause.

tunnel and feed. Pupation usually occurred on the material in the angle between the sides and the lid of the plastic container, or occasionally under the calyx lobes of the fruit. The first and second laboratory generations were used for the rearing experiments.

Eggs, larvae and pupae were reared at five constant temperatures from 20.5°C to 30.5°C (Table 1) with a 12:12 L : D photoperiod in Lindner and May temperature cabinets. Temperatures were recorded with Hastings data loggers.

Eggs

New lid material was placed on the adult containers and then removed 12 h later. Hence any eggs on the material were a maximum of 12 h old. The material was cut into pieces with eggs attached and the pieces were placed on filter paper in 90 mm plastic Petri dishes, which were sealed with Parafilm. Petri dishes containing approximately 50 eggs were placed in each temperature cabinet, inspected every 12 h, and the numbers of hatched eggs recorded and larvae removed at each inspection. Numbers of unhatched eggs were recorded.

Larvae and pupae

Three or four large eggplant fruit, purchased from a major grocery store, were placed in each plastic container and four neonate (<24 h old) larvae from the laboratory colony were placed on each fruit using a fine paintbrush. Two containers (i.e. 24–32 larvae) were placed in each temperature cabinet. The containers were examined at the same time each day and the emergence of larvae from the fruit was recorded. The end of the larval stage and the start of the pupal stage was deemed to have occurred when the larva had woven, and was enclosed by, its silken cocoon. The cocoons, which were removed carefully from the pupation sites by cutting the material or calyx lobes, were placed in glass livestock tubes (100 mm by 25 mm) with gauzed lids, and held in the temperature cabinets. They were examined daily and the time to moth emergence recorded to determine the duration of the pupal stage. While there is a pre-pupal stage in the insects' development, the pupal stage reported here includes both the pre-pupal and pupal stages as it was not possible to see through the silken cocoon to determine when the change from pre-pupa to pupa occurred.

For each developmental stage it was assumed that each insect had just started the stage when it was placed in its temperature regime and had just metamorphosed to the next stage at the time of recording. Linear regression lines of developmental rate against temperature for each stage were fitted using the data for individual insects using GenStat Release 9.2. Developmental zeroes and thermal constants were determined from the regression equations and their standard errors calculated (Campbell *et al*. 1974). Moths had not emerged from four of the cocoons at 20.5°C 3–4 weeks after the remainder of the cohort had eclosed, and examination of the cocoons showed the insects were still alive as pre-pupae within the cocoons. These four individuals were excluded from the calculations.

RESULTS

Table 1 shows the durations of each developmental stage at each of the five temperatures and the percentage of individuals that developed to the next stage.

As the temperatures used were within the straight line section of the developmental rate–temperature curve, the thermal summation model was fitted to the data. The regression equations for the thermal summation model for each stage are:

$$\text{Eggs: } y = 0.0163T - 0.183\ (R^2 = 0.896)$$

$$\text{Larvae: } y = 0.00557T - 0.067\ (R^2 = 0.669)$$

$$\text{Pupae: } y = 0.00934T - 0.135\ (R^2 = 0.842)$$

where y is 1/time (days) and T is temperature (°C). Table 2 presents the developmental zeroes and thermal constants derived from the equations.

DISCUSSION

Davis (1964) reported that under the warm conditions of spring and summer in north Queensland durations of the egg, larval and pupal stages of *S. cordalis* were 4–5 days, 10–13 days and 7–14 days, respectively. These values are similar to those recorded in the mid-range of temperatures used in this study. This study has provided more detailed information on the developmental rates for each life stage of *S.*

Table 2 Developmental zeroes and thermal constants for *Sceliodes cordalis* eggs, larvae and pupae

	Eggs	Larvae	Pupae
Developmental zero ± SE (°C)	11.22 ± 0.35	12.03 ± 0.86	14.43 ± 0.49
Thermal constant ± SE (day-degree)	61.32 ± 1.48	179.60 ± 11.52	107.03 ± 4.65

cordalis at constant temperatures. This information can be used to model the pest's population dynamics, understand its development in a crop or decide on management tactics needed to control eggs and neonate larvae before the larvae tunnel into the fruit where they are protected from insecticides.

The range of temperatures used in this study clearly was in the linear portion of the developmental rate curve, making the thermal summation model an appropriate one to use. This model is widely used as it is easy to calculate and apply, usually yields approximately correct values (Wagner *et al*. 1984) and provides good estimates of insect development at temperatures normally experienced by the insect (Kitching 1977). It would be necessary to rear the insect at a greater range of temperatures including low and high temperatures in the non-linear portions of the curve to meaningfully apply any of the non-linear models. It also would be useful to rear the insects under fluctuating temperatures as developmental times under fluctuating temperatures may differ from those predicted from studies at constant temperatures (Allsopp *et al*. 1991).

Temperature, over the range used, appeared to have little to no effect on survival of *S. cordalis*. Between 10% and 30% of eggs failed to hatch, with more failing at 20.5°C than at 28.0°C and 30.5°C. However whether the eggs failed to hatch because they were infertile or the developing larva had died was not recorded, so no conclusions on the effect of temperature on this difference can be drawn. There were no obvious differences between temperatures in the survival of larvae and all pupae developed to the adult stage at all temperatures.

The failure of the four *S. cordalis* pre-pupae at 20.5°C to develop into moths 3–4 weeks after the rest of the cohort probably indicates that they had entered diapause. After the cocoons were examined they were returned to the temperature cabinet. The temperature was raised to 25°C and one insect pupated and emerged as an adult within 3 weeks. The remaining three remained as pre-pupae for 7 weeks, so the temperature was reduced to 20°C for 4 weeks and then to 17°C for 5 weeks to simulate cooler winter conditions before being increased to 25°C and the photoperiod increased to 16:8 L : D. Two of the insects then pupated and developed into adults in 2 and 4 weeks, and the final insect was discarded as it failed to pupate after a further 2 weeks. Galbreath and Clearwater (1983) and Martin (1999) reported that in New Zealand *S. cordalis* larvae entered pre-pupal diapause in April to overwinter until October, and Martin (pers. comm. 2008) suggested that diapause is induced by a combination of temperature and day length. It is not known whether the 20.5°C temperature or the 12:12 L : D day length was most responsible for inducing diapause in the insects in this study. This demonstrated ability of members of an Australian population of *S. cordalis* to enter diapause shows they have the ability to survive cold winters, although records of *S. cordalis* moths being trapped all year round in north Queensland (Brown 2002, 2005) and in the Bundaberg district, albeit with smaller catches in the cooler months (I Kay unpubl. data 2008), indicates that diapause in *S. cordalis* is not obligative.

Clearly much more remains to be learnt about the biology and ecology of *S. cordalis*. Its seasonal history across much of Australia is unknown, as are the factors that induce and terminate diapause.

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