Temperature Requirements for Development and Oviposition of the Carrot Weevil[1,2]

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ABSTRACT

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Laboratory studies were conducted to determine temperature thresholds and thermal requirements for development and reproduction of the carrot weevil, *Listronotus oregonensis* (LeConte), using a 16:8 L:D photoperiod and temperatures ranging from 7.2 to 32.3°C. Development rate, increased linearly with increasing temperature. Calculated thresholds and centigrade degree days (CDD) necessary for development were: egg, 9.5°C and 90 CDD; larvae, 6.7°C and 264 CDD; prepupae, 7.8°C and 107 CDD; pupae 7.2°C and 128 CDD; and total development from egg to adult, 7.0°C and 623 CDD. No oviposition occurred at 12.7°C with a threshold of 14.8°C and 131 CDD necessary for newly emerged carrot weevils to oviposit. The number of eggs laid per day increased as temperature increased, from 18.3 to 29.4°C, but at 32.3°C the number of eggs laid was reduced and the preoviposition period increased, indicating that the latter temperature was unfavorable for oviposition. Validation of laboratory data indicated a satisfactory fit between expected and observed development under field conditions.

The carrot weevil, *Listronotus oregonensis* (LeConte), is a pest of increasing importance in the muck vegetable growing regions of Ohio. It feeds and develops on a variety of horticultural and weed hosts (Pepper 1942, Ryser 1975), and can be a major pest limiting production of carrots (Harris 1926, Wright and Decker 1957), parsley (Semel 1957), and celery (Pepper 1942).

Timing of insecticide applications is critical to obtain effective control of the carrot weevil. Information is available on aspects of life history and development of the carrot weevil (Wright and Decker 1958, Martel et al. 1975b, 1976, Whitcomb 1965, Pepper 1942, Ryser 1975), but it is incomplete or contradictory, and temperature thresholds for development and oviposition have not been reported. These data are needed for use in conjuction with baited traps, as developed by Ryser (1975), and modified by Grafius and Otto (1979), for timing insecticide application and studying population biology and dynamics of the carrot weevil.

Materials and Methods

Laboratory Studies

A laboratory colony of carrot weevil, begun from field-collected adults and pupae, was maintained on carrots by the method developed by Roberts and Stevenson (1975) at 16-h light (29 ± 3°C) and 8-h dark (18 ± 3°C) photoperiod. Studies on the development of the carrot weevil were conducted in environmental chambers maintained at a 16:8 L:D photoperiod, at 7.2, 10.0, 12.7, 18.3, 23.9, 26.7, 29.4, and 32.3 ± 1°C, and under a fluctuating temperature that ranged from 29.4°C (16-h day) to 18.3°C (8-h night). Humidity was not regulated but was maintained between 50 and 70%.

Eggs <24 h old were collected from the laboratory colony by using a 000 Red Sable brush, and placed on moist filter paper in 5.5-cm plexiglass petri dishes containing a carrot slice. One egg was placed in each dish. Eggs were observed daily, and the date of hatch was recorded. When carrots became unsatisfactory for feeding, larvae were carefully transferred to new carrots by brush.

The point at which larvae would leave the carrot slice and no longer feed was considered the beginning of the prepupal stage. The length of the larval period was recorded, and prepupae were placed in petri dishes containing 1 to 2 cm of moist muck soil. Prepupae were observed daily until pupation and subsequent adult emergence. At temperatures where high mortality occurred at later stages (prepupae and pupae), individuals entering that stage <24 h old were added. Regression analyses on the rate of development as a function of temperature were calculated for each stage and for total development from egg to adult. Those temperatures at which no development was observed or which were above the maximum development rate were not used in these calculations.

Newly emerged adult carrot weevils (ca. 24 h old) were collected and sexed by the method of Whitcomb (1965). Single pairs were placed in plastic petri dishes containing a carrot slice to oviposit, and 9 to 13 dishes each were placed at 10.0, 12.7, 18.3, 23.9, 29.4, and 32.3 + 1°C with a 16:8 L:D photoperiod. Carrot slices were checked daily for eggs and replaced as necessary. The number of days from emergence to oviposition was recorded, as well as the number of eggs laid daily. After a female had begun ovipositing, the tests were continued for ca. 7 to 14 days before temination. The total length of oviposition period was not measured. Any females which had not begun ovipositing by the end of the test were not considered in estimates of pre-oviposition period length.

Field Studies

Celery, carrots, and parsley plants were collected weekly from early May through September 1980 at the OARDC, Muck Crops Branch, Willard, Ohio, to validate laboratory results on development and oviposition of the carrot weevil. Time of occurrence of develop-

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mental events was calculated on the basis of heat unit accumulation from daily maximum-minimum termperatures recorded at the station. Field data using thresholds calculated for development of specific stages and overall development from egg to adult were compared with those for laboratory development. Event occurrences in the field were noted, and tempratures accumulated to the next developmental stage. Similar data for oviposition were compared with laboratory data based on adult activity in the spring and first-generation adult emergence in the summer.

Results and Discussion

Carrot weevil development generally increased directly with temperature (Table 1). Eggs did not hatch at 7.2°C. Percent hatch increased with increasing temperatures from 10.0 to 26.7°C. Larval mortality was generally high and was caused primarily by difficulties in handling. Transferring larvae only as necessary reduced mortality and the effect of handling on development. Development at lower temperatures (10.0 to 12.7°C) was slow, and no prepupal stage was observed below 12.7°C. Pupal mortality was generally lower than was observed for larvae and prepupae. The range of development of the pupal stage was similar to that of the larval and prepupal stages. These data agree with those of Martel et al. (1975), who indicated that overall survival during development of the carrot weevil was optimal in the range from 18.3 to 26.7°C.

There is some confusion in the literature about the duration of the larval and prepupal stages. In general, the data in Table 1 agree with those reported by others for total development times: Martel et al. (1976), Whitcomb (1965), and Ryser (1975). However, we report longer prepupal times than Ryser (1975) or Whitcomb (1965). This appears to be essentially a difference between definitions of when the prepupal stage begins. In this study larvae were considered to become prepupae when they discontinued feeding, exited from the carrot slice, and began to form a pupal cell. Others (Ryser 1975, Whitcomb 1965) considered the true prepupal stage to last only for a short period of time between formation of the pupal cell and larval quiescence before pupation. We thought that a line of demarcation in the larval stage feeding in the host plant and the larval stage after exiting the host plant should be established.

Linear regression analyses were calculated for each stage of development and for total development. For each stage, only those points which would indicate increasing development rates as a function of temperature were used in our calculations. Once the maximum rate of increase was reached and development rates no longer increased with increasing temperature, further values were not used to develop a linear equation. The linear equations calculated of the form $y = a + bx$ are given in Table 2. The X-intercepts represent calculated developmental thresholds for each stage or combination of stages. In each case the observed data were adequately described by a linear regression model, as indicated by high r^2 values.

Development rates and base temperatures for each stage were used to calculate centigrade degree days (CDD) necessary for development of the different stages of the carrot weevil (Table 2). In laboratory studies 590 CDD, using thresholds calculated for each stage, and 630 CDD, using a threshold of 7.0°C calculated for total development, were necessary for development of the carrot weevil from egg to adult. We calculated degree days from other reports on carrot weevil development

Table 1.—Days required for development of the carrot weevil reared at laboratory-controlled temperatures[a]

	Days[b] required for:				
Temp. (°C)	Egg	Larva	Prepupa	Pupa	Total development
10.0	45.7 ± 1.20 11	101[c] 1	— —	— —	—
12.7	31.4 ± 2.00 18	43.4 ± 1.04 9	22.9 ± 1.02 16	31.8 ± 2.43 8	129.5
18.3	12.8 ± 0.57 34	15.3 ± 0.45 13	9.5 ± 1.15 9	10.2 ± 0.63 6	47.8
23.9	7.1 ± 0.18 35	13.1 ± 0.49 14	6.5 ± 0.39 12	6.8 ± 0.20 10	33.5
25.7[d]	6.4 ± 0.40 33	13.3 ± 1.08 18	6.1 ± 0.73 15	6.5 ± 0.39 13	32.3
26.7	6.6 ± 0.66 54	13.4 ± 0.49 22	5.0 ± 0.46 14	5.8 ± 0.15 14	30.8
29.4	4.8 ± 0.10 43	11.9 ± 0.66 15	5.0 ± 0.22 16	5.8 ± 0.15 23	27.5
32.3	4.1 ± 0.07 93	12.8 ± 0.75 19	5.1 ± 0.48 14	5.2 ± 0.09 17	27.2

[a] No development was observed at 7.2°C.
[b] Values represents mean ± standard error. Second values indicate number of individuals completing each stage. Due to high mortality at 12.7, 18.3, 29.4, and 32.3°C, additional individuals were supplemented at the prepupal and pupal stages.
[c] Only one larva survived to the prepupal stage.
[d] Fluctuating temperature of 29.4°C (16 h) and 18.3°C (8 h). Corresponded with L:D photoperiod.

Table 2.—Regression equations, thresholds, and CDD required for development of the carrot weevil

Stage	No. of temperatures	Regression equation	r^2	Threshold (C°)	Stage-specific CDD[a]	Total-development CDD[b]
Egg	8	$\hat{y} = -0.0941 + 0.00099X$	0.97	9.5	90	130
Larva	5	$\hat{y} = -0.0296 + 0.0044X$	0.92	6.7	264	256
Prepupa	6	$\hat{y} = -0.0759 + 0.0097X$	0.97	7.8	108	114
Pupa	7	$\hat{y} = -0.0587 + 0.0082X$	0.96	7.2	128	130
Egg through Adult	6	$\hat{y} = -0.0119 + 0.0017X$	0.98	7.0	590	623

[a] CDD necessary for development based on thresholds calculated for each stage.
[b] CDD necessary for development based on the threshold calculated for total development (7.0°C).

and obtained values of 558 CDD (Whitcomb 1965), 532 CDD (Martel et al. 1976), and 650 CDD (Ryser 1975), using a threshold of 7.0°C.

Data available on oviposition of the carrot weevil have been concerned with the effects of both light and temperature on oviposition. The literature is well documented with cases on late-season adults not laying egg due to photoperiod (Whitcomb 1968, Ryser 1975, Pepper 1942), and this has been observed in Ohio.

Our study was concerned only with the effect of temperature during the prepoviposition period and initial number of eggs laid. These data (Table 3) show a decrease in length of preoviposition period and an increase in eggs per ♀ per day up to 29.4°C. Above this temperature, preoviposition period increases and number of eggs per day decreases. A linear regression calculated for the preovipositional period (reproductive development per day) as a function of temperature was $\hat{y} = -0.1198 + 0.00752X$ ($r^2 = 0.99$) based on the period of time from adult emergence to egg laying rather than from adult mating to egg laying as studied by Wright and Decker (1958). The ovipositional threshold was calculated to be 14.8°C, and 131 CDD were necessary for oviposition. At this point we can only determine that, under optimal laboratory conditions of light, this relationship does exist. It remains to be determined what interrelationships may exist between light and temperature on certain other aspects of reproductive development such as male and female reproductive maturity, egg formation, sperm viability, etc.

Field Studies

Table 4 shows results of field validation studies conducted May through September 1980. We calculated heat units accumulated based on maximum-minimum temperatures by using a sine wave equation similar to that reported by Allen (1976). Comparing expected accumulated temperatures for an event to occur under field

Table 3.—Laboratory studies on preoviposition period and egg laying of the carrot weevil

Temp. (°C)	No. of pairs	% Ovipositing	Preoviposition period (days)[a]	Range (days)	No. of eggs/♀ per day[a]
10	10	0	0	0	0
12.7	9	0	0	0	0
18.3	11	64	34.6 ± 2.26	27–42	2.0 ± 0.30
23.9	13	77	15.6 ± 1.22	10–24	3.3 ± 0.42
29.4	10	100	8.9 ± 1.08	6–14	5.8 ± 0.44
32.3	12	83	18.1 ± 2.54	9–36	3.1 ± 0.86

[a] Mean ± SE.

Table 4.—Field validation of developmental studies based on total-development and stage-specific thresholds for the carrot weevil

Generation, stage	CDD Experimental (7.0°C)	CDD Observed (7.0°C)	CDD Experimental (stage specific)	CDD Observed (stage specific)
First				
Eclosion	130.2	125.5	90.2	91.3
Pupation[a]	370.5	374.5	372.0	386.9
Adult emergence	129.8	135.1	127.8	133.1
Second				
Eclosion	130.2	133.0	90.2	113.1
Pupation[a]	370.5	382.1	372.0	382.7
Adult emergence	129.8	121.4	127.8	119.0
$\Sigma\,(0\text{-}E)^2/0$	1.40[b]		7.60[b]	

[a] Includes larval + prepupal development.
[b] No significant difference ($P > 0.05$) between observed and expected development when tested by the χ^2 goodness-of-fit test.

conditions with observed events for both stage-specific thresholds and an overall developmental threshold of 7.0°C, we were unable to show significant differences ($P = 0.05$) by a goodness-of-fit test. Similar information for oviposition resulted in 40 CDD (from 1 January 1980) for oviposition of overwintered adults. These data did not support our laboratory data of 131 CDD, but this indicates that factors are involved in oviposition of overwintered adults which have not been investigated. For newly emerged first-generation adults 139 CDD were calculated before oviposition began, which does agree with our laboratory data.

The fact that mated, reproductively mature females will overwinter and produce viable eggs in spring without mating again was indicated by Ryser (1975) and was observed in laboratory tests in Ohio from females which had been collected from field plots before they became active (Simonet, unpublished data). Thus, this information will be most useful in following the egg deposition of newly emerging adults.

An initial key to studying the population structure and dynamics of the carrot weevil is to have a reasonable idea of what part temperature may play in development and population growth. Use of laboratory-generated data and field validation of development and oviposition can be most useful in timing sampling intervals and spray applications and in following population development.

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