

Development of *Diaprepes abbreviatus* (Coleoptera: Curculionidae) on Artificial and Citrus Root Substrates

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J. Econ. Entomol. 91(5): 1173-1179 (1998)

ABSTRACT Measurement of head capsule widths showed that larvae of *D. abbreviatus* generally have 10 or 11 instars when reared on artificial diet. The growth ratio for head capsules was greater during stadia for the 1-5th instars and declined after the 6th. Head capsule widths and larval growth increased steadily for 71 d, at which time, all larvae were 7-10th instar. Larval growth reached a plateau at 114 d during stadia at 9-11th instar and remained unchanged to 188 d. The mean time for development of 1st to 7th instars was less compared with instars >7th. A frequency distribution based on head capsule size for greenhouse- and field-collected larvae fed citrus roots over time had similar stadia peaks to larvae reared on artificial diet in the laboratory. Weight of larvae with head capsule widths <1.0 mm increased slowly within stadia, whereas a greater increase in larval weight was observed for larvae with capsule widths >1.0 mm. Variation in larval weight for each stadium was also greater for larvae with head capsule widths >1.0 mm. Most larval weight gain occurred during stadia at 6-8th instar, suggesting higher food consumption at these developmental stages. Larval weight increased steadily within the initial 71 d but declined slowly thereafter. The mean weight for instars reared on artificial diet was greater than for either greenhouse- or field-collected larvae. The mean weight for larvae fed citrus roots in the greenhouse was smaller than for larvae feeding on roots in the field. On artificial diet, only a few larvae developed to pupae. Approximately 70% of the larvae pupated at the 10th instar, whereas others pupated at the 11th instar. The mean time \pm SEM required for larval development to pupae, larvae to adult, and pupae to adult was 153.3 \pm 28.0 d, 158.3 \pm 20.7 d, and 17 \pm 3.8 d, respectively. Mean larval weight before pupation was 450.4 \pm 102.5 mg, mean pupal weight 378.2 \pm 66.1 mg, and mean adult weight 276.0 \pm 51.6 mg. Larvae lost 20.3% of their live weight during metamorphosis to pupae and pupae lost 24.7% of their live weight in becoming adults.

KEY WORDS *Diaprepes abbreviatus*, root weevil, developmental biology, insect rearing

Diaprepes abbreviatus L., a root weevil native to the Caribbean region (Woodruff 1985), has emerged as a major localized pest of citrus and ornamental plants in Florida since its introduction in 1964 (Woodruff 1964, McCoy and Simpson 1994). Of the 270 plant associations recorded, many agricultural plants, including sugarcane, pineapple, corn, peanuts, potato, and cassava, serve as larval hosts (Simpson et al. 1996). *D. abbreviatus* is likely a univoltine species with 3 immature stages; egg, larva, and pupa. The adult, egg, and neonate stages appear on the host plant above ground and all larval stages, and the pupa and teneral adult occur below ground. Upon hatch, neonates fall from the leaf to the soil surface beneath the tree where they enter the soil (Wolcott 1936). Although larval behavior in the soil is poorly understood, larval size appears to dictate the site of root feeding (Beavers and Selhime 1975). Tiny neonates (0.5 cm long) feed on fibrous roots, whereas later instars also feed on larger

lateral roots, forming deep grooves as they consume the outer bark, including the cambium layer. Larvae remain on the roots for 8-15 mo, reaching 1.3-2.5 cm in length (Wolcott 1936). Larger larvae can remove the outer bark from the crown area of the root system or girdle the trunk found below the soil surface thereby killing the tree. The protracted period in the soil as larvae includes an inactive pupal stage of 2-4 wk (Wolcott 1936, Beavers and Selhime 1975). The aboveground symptoms associated with extensive root injury, such as leaf yellowing or leaf drop, twig dieback, off blooming, fruit drop, and heavy crop set, are similar to other tree declines caused by root maladies. Larval injuries by *D. abbreviatus* serve as preferred infection courts for root rot diseases of citrus caused by soil pathogens such as *Phytophthora* spp. (Rogers et al. 1996).

Numerous reports on specific aspects of the biology and life history of *D. abbreviatus* on different hosts has been reported previously (Wolcott 1933, 1934, 1936; Beavers and Selhime 1975; Beavers 1982), yet some difference of opinion exists, particularly in relation to larval ecdysis and developmental time. Because a detailed knowledge of larval development is vital to our

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understanding of the population dynamics, host plant relationships, and models addressing integrated pest management (IPM) strategies for the weevil, studies were initiated to determine larval stages based on age, body weight, and head capsule widths in relation to ecdysis. In addition, pupal and adult development were addressed.

Materials and Methods

Insects. Larvae of *D. abbreviatus* were obtained from the rearing facility at the U.S. Horticultural Research Laboratory, USDA-ARS, Orlando, FL. The artificial diet and rearing procedures used for larval production were similar to those described by Beavers (1982). Larvae were held in the laboratory at $27 \pm 2^\circ\text{C}$ in a semidark room during development. A cohort of larvae, held individually in plastic cups (30 ml) containing artificial diet for 1, 4, 10, 17, 25, 31, 36, 44, 50, 59, 71, 78, 87, 107, 114, 121, 124, 127, 133, 153, 162, 176, 181, and 188 d were selected randomly from the stock supply and sent overnight to the Citrus Research and Education Center, University of Florida, Lake Alfred, FL. They were held at $27 \pm 2^\circ\text{C}$ at 75–80% RH in complete darkness until processed.

Determination of Stadia. A total of 682 larvae was selected randomly for head capsule measurements. For each larval age, ≈ 30 head capsule widths were carefully measured with an ocular micrometer attached to a dissecting microscope. The head capsules for stadia <5th instar was measured at $50\times$ cap, whereas others were measured at $12\times$ cap magnification. All measurements were performed within a 4-d period. Larval age was calculated from the time of each measurement. A frequency distribution of the head capsule widths for each age group was plotted to estimate instar number. Additional head capsule measurements were made before and after molting to confirm the instar representative of a given peak in the frequency distribution. In the case of 1st–4th instars, individuals were held in 30-ml clear plastic cups containing a moisten filter paper disc (1.5 cm diameter) and a thin slice of raw carrot as a food source rather than in diet to improve detection of exuviae. Other stadia were fed diet. Every other day, larval ecdysis was confirmed by the presence of the exuviae.

Larval stadia also were determined by measuring head capsules for larval cohorts of different weight in relation to ecdysis. Larval weight for each age class was determined for 560 individuals by using a precision balance. In addition, the time required for larval development to pupae, larval development to adult, and pupal development to adult was recorded along with their respective weights.

Validation of Instar by Using Head Capsule Measurements from Larva Recovered from Greenhouse and Field Soil. For comparative purposes, 50 container-grown (15.2-cm plastic pots) 'Sunburst' mandarin seedlings propagated in Candler soil were each infested with 25 neonates. The seedlings were maintained on a greenhouse bench for 8 wk at an ambient temperature of $27 \pm 2^\circ\text{C}$. Seedlings were watered

twice weekly and fertilized monthly. At 8 wk, each seedling was removed from its container. Soil surrounding the roots and that remaining in each container were sieved to recover surviving larvae. A total of 50 larvae of various sizes was then processed using the previously described procedure to determine larval instar and weight. In addition, head capsule and larval weight determinations were made for 226 larvae collected from 9-m³ field soil taken from the rhizosphere of a planting of 50 'Flame' grapefruit (3 yr old) on Swingle citrumelo rootstock. These trees had been infested with 7,000 neonates during April through June 1997 before they were uprooted in September.

Statistical Analysis and Modeling. Correlation and data plotting analysis were applied to test the relationships for cephalic capsule widths (millimeters) with instar, cephalic capsule widths (millimeters) with age, cephalic capsule widths (millimeters) with larval weight, larval weight with instar and instar with time. SAS NLIN procedure was used to calculate the parameters for potential models.

Results

Statistical analysis showed clear and positive logistic trends for the above-mentioned relationships. The model found to describe these relationships is

$$y = \frac{a - d}{1 + \left(\frac{x}{c}\right)^b} + d,$$

where a and d are the minimal and maximal levels of the dependent variable, respectively; b is the slope of the model; and c is the value of the independent variable at which the corresponding dependent variable value is the mean. The point is also where the curve changed from concave to convex. A frequency distribution of head capsule widths and some exuviae identifications for 682 larvae showed a range from 0.2 to 3.6 mm and revealed 11 distinct modal peaks (Fig. 1A). Head capsule widths for each age group determined before and after molting for each instar is expressed as a mean and range of variability (Table 1). The growth ratio for head capsule widths was greater for the 1st–5th stadia and declined after the 6th stadium (Table 1). The mean growth ratio for 1st–5th stadia was 1.4 and for other stadia 1.2. Only the mean growth ratio for 1–5 instar fit Dyar's rule (Dyar 1890). Some 10th instars molted without a change in the size of the head capsule. The relationship between head capsule widths and instar appeared to best fit the logistic model ($r^2 = 0.998$) (Fig. 2B).

$$y = \frac{0.2679 - 3.1408}{1 + \left(\frac{x}{20.2618}\right)^{2.8901}} + 3.1408 \quad (P < 0.0001), \quad [1]$$

where y represents larval head capsule widths and x the larval instar. The model suggests the highest growth rate for the larval head capsule widths occurred at 7th–8th instar and even a larger head capsule width would be identified for supernumerary larvae.

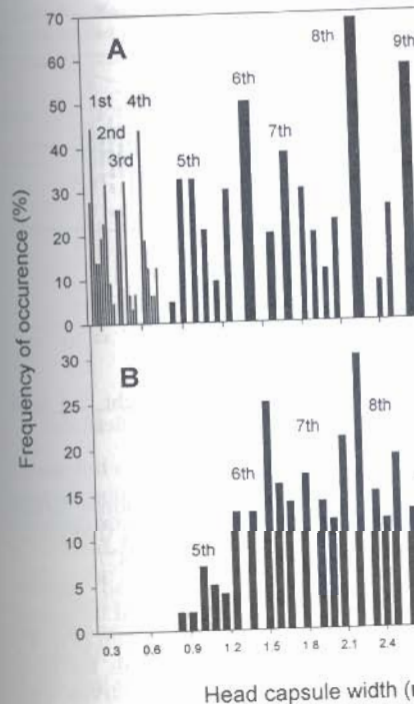


Fig. 1. Frequency distribution of larval widths of *D. abbreviatus* reared on artificial diet collected from greenhouse and field citrus (682).

According to frequency distribution, capsule size for greenhouse and field-collected larvae were similar to the peak for the age group with capsule widths >0.8 mm reared on artificial diet in the laboratory (Fig. 1B). No larvae with capsule widths <0.8 mm in width were recovered from field house and field soils because of the viscid nature of the soil to detect such small larvae.

Larval head capsule widths increased during the first 71 d but remained constant thereafter. The relationship between head capsule widths and instar was described by the logistic model $r^2 = 0.998$.

Table 1. Head capsule measurements for *D. abbreviatus* reared on artificial diet at $27 \pm 2^\circ\text{C}$.

Larval stage	n	Head capsule widths (mm)	
		Mean \pm SEM	Δ
1	36	0.26 \pm 0.02	
2	22	0.35 \pm 0.02	0.09
3	31	0.47 \pm 0.04	0.12
4	16	0.65 \pm 0.04	0.18
5	43	0.99 \pm 0.09	0.34
6	50	1.39 \pm 0.12	0.40
7	60	1.81 \pm 0.10	0.42
8	57	2.22 \pm 0.09	0.41
9	116	2.64 \pm 0.11	0.42
10	205	3.03 \pm 0.10	0.39
11	75	3.31 \pm 0.07	0.27

* Growth ratio of each stadia was obtained by dividing the head capsule widths of an older instar by its preceding instar.

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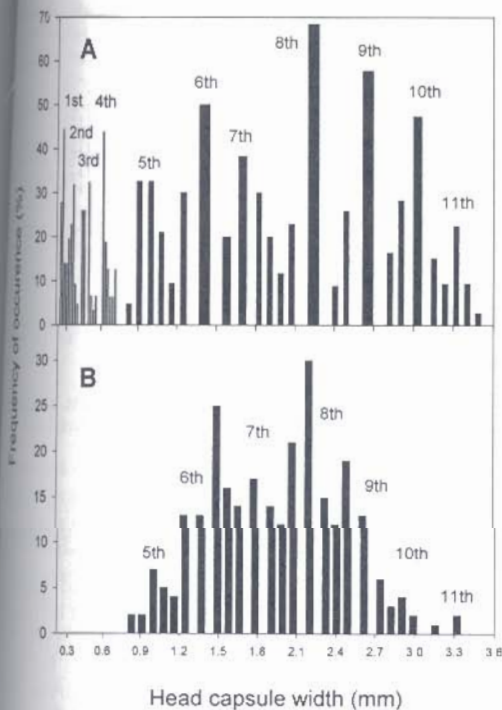


Fig. 1. Frequency distribution of larval head capsule widths of *D. abbreviatus* reared on artificial diet (A) and collected from greenhouse and field citrus roots (B) ($n = 682$).

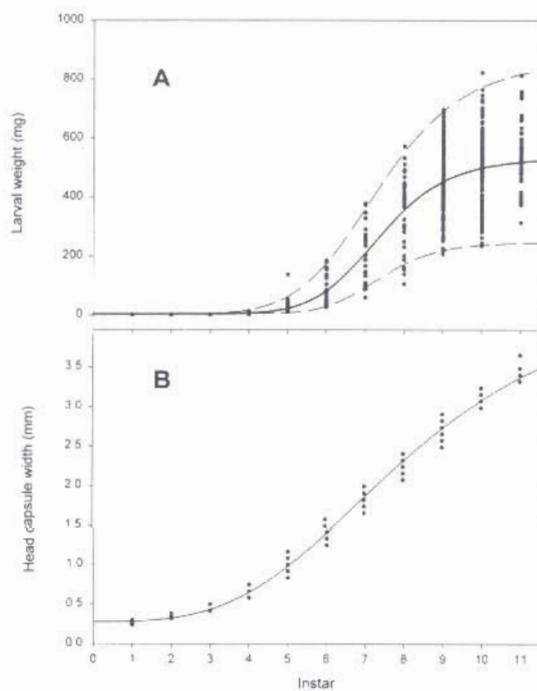
According to frequency distribution, peaks for head capsule size for greenhouse and field-collected larvae were similar to the peak for the age groups with head capsule widths >0.8 mm reared on artificial diet in the laboratory (Fig. 1B). No larvae with head capsules <0.8 mm in width were recovered from the greenhouse and field soils because of the visual difficulty to detect such small larvae.

Larval head capsule widths increased steadily for 71 d but remained constant thereafter. The relationship between head capsule widths and time is best described by the logistic model $r^2 = 0.9889$) as follows:

Table 1. Head capsule measurements for larval stages of *D. abbreviatus* reared on artificial diet at $27 \pm 2^\circ\text{C}$

Larval stage	n	Head capsule widths (mm)			Ratio ^a growth
		Mean \pm SEM	Δ	Range	
1	36	0.26 \pm 0.02		0.24-0.30	
2	22	0.35 \pm 0.02	0.09	0.32-0.40	1.35
3	31	0.47 \pm 0.04	0.12	0.42-0.56	1.34
4	16	0.65 \pm 0.04	0.18	0.58-0.75	1.40
5	43	0.99 \pm 0.09	0.34	0.83-1.16	1.52
6	50	1.39 \pm 0.12	0.40	1.24-1.58	1.40
7	60	1.81 \pm 0.10	0.42	1.70-1.99	1.30
8	57	2.22 \pm 0.09	0.41	2.07-2.41	1.23
9	116	2.64 \pm 0.11	0.42	2.49-2.82	1.20
10	205	3.03 \pm 0.10	0.39	2.90-3.23	1.15
11	75	3.31 \pm 0.07	0.27	3.24-3.65	1.10

^aGrowth ratio of each stadia was obtained by dividing the head capsule widths of an older instar by its preceding instar.



The relationship between weight (A) and head capsule width (B) with instar age of larvae of *D. abbreviatus*

Fig. 2. Relationship between larval weight (A) and head capsule width (B) and stages of *D. abbreviatus* reared on artificial diet.

$$y = \frac{0.2792 - 4.5878}{1 + \left(\frac{x}{8.2722}\right)^{3.2605}} + 4.5878 \quad (P < 0.0001), \quad [2]$$

where y represents larval head capsule widths and x time in Julian days (Fig. 3B).

The relationship between instar and time is shown in Fig. 3C. As was true for head capsule widths, larval development increased gradually for 71 d. At this time, larvae were at 7-10th stadia. Larval growth reached a plateau at 114 d at 9-11th instar and remained unchanged until 188 d. The following logistic model ($r^2 = 0.9917$) described the relationship between instar and time:

$$y = \frac{0.6506 - 10.3417}{1 + \left(\frac{x}{30.7497}\right)^{2.0547}} + 10.347 \quad (P < 0.0001), \quad [3]$$

where y represents larval instar and x time in Julian days.

The mean time for development of 1-7th stadia was less compared with larvae >7 th (Table 2). For example, the stadium for 1st-2nd instar larvae took 5.1 d compared with 37 d for 8th to 9th instar. Only a few larvae examined developed to pupae on the artificial diet probably because conditions within the cups were unfavorable. The mean time \pm SEM required for lar-

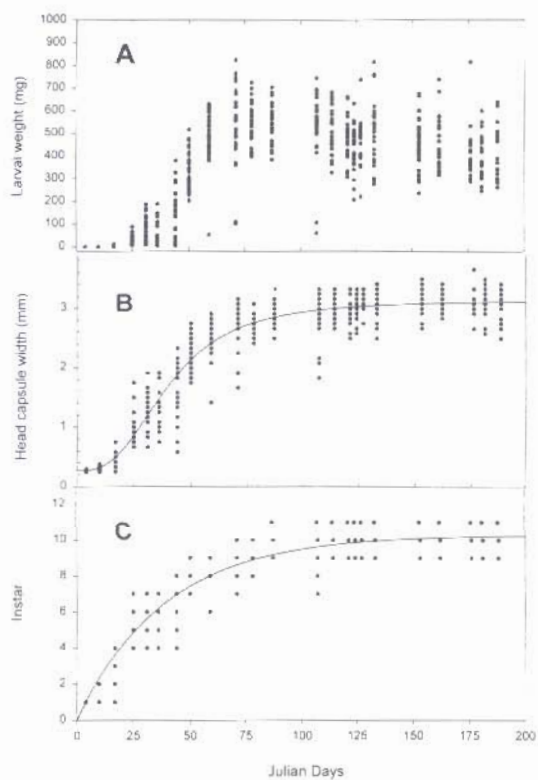


Fig. 3. Relationship between larval weight (A) head capsule width (B) and instar (C) with Julian day age for *D. abbreviatus* reared on artificial diet.

vae to develop to pupae, larvae to adult, and pupae to adult were 153.3 ± 28.0 d ($n = 35$), 158.3 ± 20.7 d ($n = 24$), and 17 ± 3.8 d ($n = 7$), respectively. The mean larval weight before pupation was 480.4 ± 102.5 mg ($n = 34$). The mean pupal and adult weight were 378.2 ± 66.1 mg ($n = 52$) and 276.0 ± 51.6 mg ($n = 27$), respectively. Larvae lost 97.5 ± 68.7 mg or 20.3% of their body weight during metamorphosis to pupae ($n = 34$) and the pupae lost 93.3 ± 33.9 mg or 24.7% of their body weight in becoming adults ($n = 27$). Most of the larvae pupated at the 10th instar (70%); the remainder at the 11th. No larvae were observed

Table 2. Time required for larval development of *D. abbreviatus* reared on artificial diet $27 \pm 2^\circ\text{C}$

Stadium	n	Mean developmental time (d) \pm SEM	Time between molts, d
1	41	7.9 ± 4.4	
2	7	13.0 ± 3.7	5.1
3	6	17.0 ± 0.0	4.0
4	15	16.4 ± 10.5	9.4
5	33	30.1 ± 5.5	3.7
6	33	34.9 ± 6.9	4.8
7	26	46.8 ± 16.4	11.9
8	33	57.9 ± 15.8	11.1
9	172	95.1 ± 36.6	37.2
10	154	130.2 ± 35.3	35.1
11	58	148.2 ± 23.7	18.0

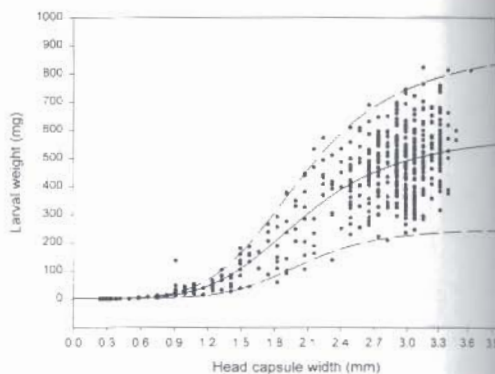


Fig. 4. Relationship between larval weight and head capsule width of *D. abbreviatus* reared on artificial diet.

pupating earlier than the 10th instar. Some larvae reached the 10th instar in 70 d suggesting that pupation is possible anytime after 71 d (Fig. 3C).

Weight increased gradually with head capsule width for larvae < 1.0 mm; however, weight increased rapidly for those with head capsules > 1.0 mm (Fig. 4). The variation in weight among individuals for each head capsule width was also greater for larvae with head capsules > 1.0 mm. The relationship between larval weight and head capsule widths appeared to best fit the logistic model ($r^2 = 0.9457$):

$$y = \frac{3.9308 - 538.05}{1 + \left(\frac{x}{7.3859}\right)^{8.4759}} + 538.05 \quad (P < 0.0001), \quad [4]$$

where y represents larval weight and x larval head capsule widths.

The relationship between larval weight and instar was similar to larval weight and head capsule width (Fig. 2A). The logistic model ($r^2 = 0.9431$) was

$$y = \frac{2.8465 - 576.89}{1 + \left(\frac{x}{2.0612}\right)^{4.6564}} + 576.89 \quad (P < 0.0001), \quad [5]$$

where y represents larval weight and x larval instar.

The larval weights for each instar are shown in Table 3. Larval weight increased linearly throughout development and greater variation in body weight was observed for larvae ≥ 5 th instar. For example, larval weight for 8th instars ranged from 106.1–572.4 mg. The mean weight gain per day among stadia was greatest at 5–7th instar suggesting that these instars cause greater root injury. Larval body weights increased steadily for 71 d but declined slowly thereafter (Fig. 3A), suggesting that larval demand for food diminished through physiological change or diet was less edible because of loss of water.

Larval body weight increased as the head capsule widths increased for larvae fed predominantly citrus roots both in the greenhouse and field and appeared to best fit the exponential model based on head capsule widths for only 5–9th instar (Fig. 5 A and B).

Table 3. Mean weight of larval stages of *D. abbreviatus* on artificial diet at $27 \pm 2^\circ\text{C}$

Instar	n	Weight (mg)		Difference in weight between instars
		Mean \pm SEM	Range	
1	41	0.4 ± 0.2	0.3–0.9	
2	7	0.6 ± 0.3	0.3–0.9	0.2
3	6	1.4 ± 0.6	0.6–2.1	0.5
4	15	7.9 ± 3.5	2.3–13.7	6.5
5	33	31.1 ± 22.2	10.0–136.7	23.3
6	33	81.9 ± 47.3	26.4–185.6	50.8
7	26	199.4 ± 95.9	59.2–378.9	117.5
8	33	359.8 ± 126.7	106.1–572.4	160.0
9	172	453.4 ± 104.8	207.9–688.7	93.3
10	154	478.6 ± 115.2	235.6–823.0	25.2
11	58	554.9 ± 111.7	315.5–813.7	76.0

Larvae fed only citrus roots in the greenhouse most of their weight at the 7th or 8th instar. In the field, body weight gain was consistent ≥ 6 th instar, except at 9th instar where gain was less. Mean body weight for larvae fed citrus roots in the greenhouse was less than for those from the field (Table 4). For example, the mean larval weight at 8th instar was 89 and 127 mg for greenhouse and field, respectively, yet, the mean weight of field-reared larvae was greater than for either greenhouse or field-collected larvae (Table 3). At the

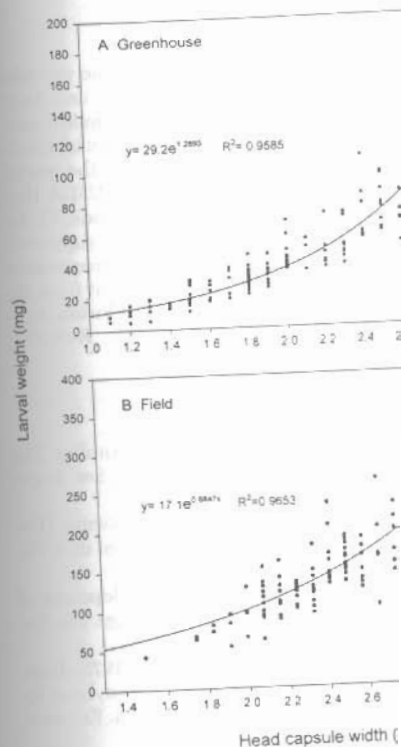


Fig. 5. Relationship between larval head capsule width of *D. abbreviatus* collected from (A) and field (B) citrus roots.

Table 3. Mean weight of larval stages of *D. abbreviatus* reared on artificial diet at 27 ± 2°C

Instar	Weight (mg)		Difference in weight between instars	Δ wt gain/d
	Mean ± SEM	Range		
4	0.4 ± 0.2	0.3-0.9		
5	0.6 ± 0.3	0.3-0.9	0.2	0.04
6	1.4 ± 0.6	0.6-2.1	0.8	0.20
7	7.9 ± 3.5	2.3-13.7	6.5	0.69
8	31.1 ± 22.2	10.0-136.7	23.2	6.27
9	81.9 ± 47.3	26.4-185.6	50.8	10.58
10	199.4 ± 95.9	59.2-378.9	117.5	9.87
11	359.8 ± 126.7	106.1-572.4	160.4	14.45
12	453.4 ± 104.8	207.9-688.7	93.6	2.52
13	478.6 ± 115.2	235.6-823.0	25.2	0.72
14	554.9 ± 111.7	315.5-813.7	76.3	4.25

Table 4. Mean weight of larval stages of *D. abbreviatus* fed on citrus roots from greenhouse and field

Instar	n	Weight (mg)		Ratio	Weight gain, mg
		Mean ± SEM	Range		
Greenhouse					
5	20	11.0 ± 5.0	4.8-19.8	2.6	17.4
6	66	28.4 ± 8.4	11.7-47.4	1.8	22.3
7	46	50.7 ± 15.7	18.7-109.3	1.8	38.8
8	31	89.5 ± 24.3	53.0-152.0	1.6	49.2
9	6	138.7 ± 28.7	106.5-190.4	—	—
Field					
6	1	41.6	—	2.0	40.0
7	11	81.6 ± 21.3	53.1-128.5	1.6	46.4
8	47	128.0 ± 34.3	61.7-233.6	1.3	42.5
9	35	170.5 ± 35.4	101.5-262.5	1.4	74.0
10	7	244.5 ± 50.6	185.2-332.5	1.2	52.4
11	2	296.9 ± 10.6	289.4-304.4	—	—

Larvae fed only citrus roots in the greenhouse gained most of their weight at the 7th or 8th stadia, according to measurements made using 5-9th instars (Table 4). In the field, body weight gain was consistent for larvae 8th instar, except at 9th instar where gain was highest. Mean body weight for larvae fed citrus roots in the greenhouse was less than for those from the field (Table 4). For example, the mean larval body weight at 8th instar was 89 and 127 mg for greenhouse and field, respectively, yet, the mean weight of laboratory-reared larvae was greater than for either greenhouse or field-collected larvae (Table 3). At the 8th instar,

larvae fed artificial diet weighed ≈3 times more than larvae fed citrus roots from the field.

Discussion

Head capsule size measurements suggest that larvae of *D. abbreviatus* have 10 or 11 instars. The possibility exists however, that larvae reared on a defined artificial diet or on roots in soil have an indeterminate number of instars. Growth ratios for head capsules for larvae >5th instar declined and were only 1.10 for 10-11th instars. In addition, some 10th instars molted without an enlargement of the head capsule. The presence of undersized head capsules or larval molts exceeding the usual number suggest a physiological response of the larvae triggered by changing environmental conditions (Huffman and Smith 1979, Williams 1976). Schroeder (1987) reported that larvae of *D. abbreviatus* grew rapidly on the artificial diet, but larvae failed to pupate in diet cups. However, 86% of the larvae from cups pupated when they were placed in soil at 50% moisture level (vol:wt) suggesting that moisture could be a factor. Wolcott (1933, 1934, 1936) observed variation in the numbers of instars of *D. abbreviatus* reared on beans and corn. He recorded from 6 to 16 molts, strongly suggesting that larvae are "indeterminate molters" that can be influenced by food source. A long developmental time as observed for *D. abbreviatus* on artificial diet also appears to favor the presence of supernumerary instars when food is abundant. This is true for *Heliothis zea*, that has both a long developmental time and supernumerary instars (Ditman and Cory 1931, Phillips and Barber 1931, Isley 1935, Boldt et al. 1975). It should be noted, however, that instar determination by Wolcott (1933) was based on visual observation of head capsules for larvae <8th instar and detection of exuviae for larvae >8th instar. The precision of his method, no doubt, was affected by larval size, because <5th instars are very small and variation in head capsule size is very difficult to determine and considerable variation in larval size within the same stadium.

Beavers and Selhime (1975) reported that head capsule widths of larvae fed sweet orange citrus seed-

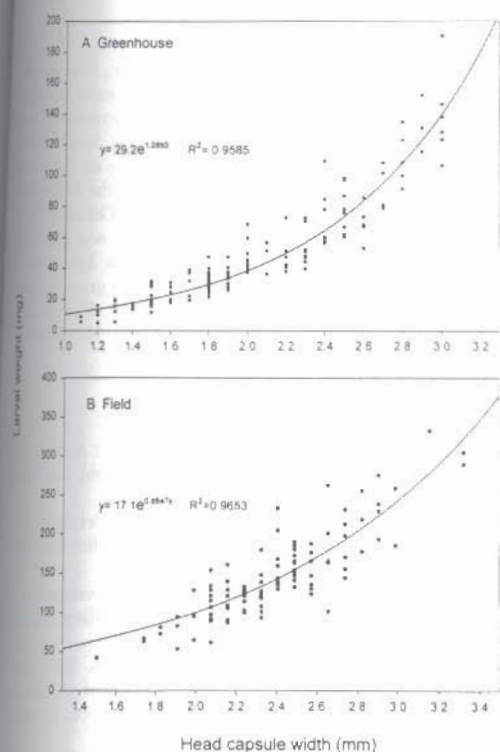


Fig. 5. Relationship between larval weight and head capsule width of *D. abbreviatus* collected from greenhouse (A) and field (B) citrus roots.

lings in the greenhouse ranged from 0.33 mm for neonates to 2.58 mm for 175-d-old larvae. In our studies, the head capsule of diet-reared larvae ranged from 0.24 mm for neonates to 3.65 mm for 150-d-old larvae and were similar to head capsules for larvae collected from the greenhouse and field. The difference in head capsule widths of neonates from our studies compared with Beavers and Selhime (1975) was small and was probably the result of variation in the magnifications used in performing the measurements. Measurements of larvae with head capsule widths <1.0 mm require a high magnification ($\geq 50\times$) to obtain precision.

Results of several studies have shown that the developmental period for larvae of *D. abbreviatus* is highly variable and it can take ≈ 1 yr (Watson 1903, Ballow 1912, Nowell 1913, Jones 1915, Wolcott 1933, Beavers 1982). Wolcott (1936) reported that the larval period of *D. abbreviatus* was extended to ≈ 1 yr by a resting period before pupation, an interval that he called active diapause. Beavers and Selhime (1975) reported that an extended diapause is not a prerequisite for the development of *D. abbreviatus* because adults were reared from citrus seedlings at 132 through 168 d after infestation with neonates. In our studies, larvae on artificial diet required a mean time of 153 d to develop to pupae and 158 d to develop to adult. Larvae of *D. abbreviatus* <7th instar exhibited rapid growth for 71 d. This rapid growth period led to a period of major physiological change characterized by lethargy where actual larval weight also declined. The mean time of pupation of 17 d we observed in our studies, was similar to other studies (Watson 1903, Beavers 1982, Schroeder 1987). Although the variability in developmental time for *Diaprepes* may have some genetic basis, it would appear that soil temperature and moisture as well as quantity or quality of food source is of importance. A better understanding of larval physiology would be particularly helpful to achieving a solution of this matter.

Mean weight for larvae produced on diet and roots showed that weight gain was greatest for 6–9th instars. These data suggest that these larval stages cause the greatest damage to citrus roots when weight gain per unit time is greater. Gain in mean body weight for larvae produced in the greenhouse on a limited citrus root source was smaller than field larvae, where food was not limited and overcrowding was unlikely. Conversely, mean body weight of field-reared larvae was lower than diet-reared larvae, probably because the later had unlimited food of high quality. It should be noted, the adult *Diaprepes* reared on artificial diet as imatures are larger than field-reared larvae on citrus roots.

Data on larval development in time have important practical implications relating to time of application of various control agents used as soil treatments at different times of the year. Because larval development is greatest during the first 3 mo after egg hatch, particularly at 5–7th instar based on maximum weight gain (Fig. 3 A and C), one can assume that active larval feeding on fibrous and woody roots is occurring at this time. Therefore, control of invasive neonates and other instars, particularly those ≤ 8 th within a 90-d

interval should minimize root injury. Because later instars (9–11) undergo physiological change that suggest reduced mobility and feeding (prepupal period), less concern should be given to their control.

Seasonal population dynamics of adult *Diaprepes* based on trapping data, suggest that peak emergence occurs in April through mid-June in central Florida with some emergence throughout the year in central Florida (unpublished data). Because adults are most abundant at this time of the year, it is safe to assume that oviposition is also at a high level, particularly in view of the fact that adults live 3–4 mo in the field and food is abundant. Because eggs require ≈ 8 –10 d to hatch at 25.6°C, we can assume that neonates are invading the soil well into the summer unless adults and eggs are controlled by foliar sprays or natural enemies.

Soil temperatures during this time of the year in shaded and unshaded citrus groves in central Florida fall within the range of the temperature used in our study (DuCharme 1971), so one can assume that larval development at this time of the year is comparable to our data presented herein. Therefore, when the 90-d period for maximum larval injury to the roots is superimposed onto the peak period of adult activity in the field, it would appear that maximum larval injury to the roots, by overlap of all instars, begins in early May and continues through July unless natural control becomes limiting.

Acknowledgments

We are very grateful to Nelson Garcia, Jr., who provided volunteer technical assistance in the laboratory and Angel Hoyte, Ian W. Jackson, and Jerry Fojtik for technical assistance with the greenhouse and field studies. Special thanks are given to Karen Crosby for her assistance on the rearing of the insects. We express our gratitude to the USDA Horticulture Research Laboratory, USDA-ARS, Orlando, FL, for furnishing larvae for this study. This work was supported in part by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA-Brasília/Brazil), and a special grant from the USDA-ARS under cooperative agreement, Florida Agricultural Experiment Station Journal Series No. R-06206.

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Received for publication 24 March 1998, accepted 30 June 1998

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