Effects of Two Prey Species on the Development of *Hippodamia sinuata* (Coleoptera: Coccinellidae) Larvae at Constant Temperatures

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ABSTRACT The effects of prey species and constant temperature regimes on the development of *Hippodamia sinuata* Mulsant were studied. *H. sinuata* completed larval development faster on corn leaf aphids, *Rhopalosiphum maidis* (Fitch), than on greenbug, *Schizaphis graminum* (Rondani), at low temperatures, but no significant differences were evident at temperatures >20°C. *H. sinuata* began development at a lower threshold temperature (7.05°C), and required more degree-days (338.63) for development when corn leaf aphids were the prey rather than greenbugs (12.90°C, 259.54). At 25 and 30°C, *H. sinuata* larvae consumed significantly more corn leaf aphids than greenbugs (both per day and total consumption), whereas significantly more greenbugs were consumed at 20 and 35°C. The results of the studies confirm the importance of corn leaf aphids as an early-season, cool-temperature prey for *H. sinuata*.

KEY WORDS Insecta, *Hippodamia sinuata*, *Schizaphis graminum*, *Rhopalosiphum maidis*

Hippodamia sinuata Mulsant, a medium-sized coccinellid (subfamily Coccinellinae, tribe Coccinellini), is an important predator of greenbugs, *Schizaphis graminum* (Rondani), on grain sorghum (*Sorghum bicolor* Moench.) in the Texas High Plains (Kring et al. 1985). Depending on climatic factors, *H. sinuata* can be more common in warmer summers than the ubiquitous *H. convergens* Guerin (Kring et al. 1985; G.J.M. & R.W.B., unpublished data).

Gordon (1985) described three subspecies of *H. sinuata: H. s. sinuata* Mulsant, *H. s. crotchi* Casey, and *H. s. spuria* LeConte. According to his descriptions, and personal communications with him, the population in the Texas High Plains is primarily *H. s. crotchi*, although examples of the other subspecies are also found. Because no distinctions were made by the authors concerning the subspecific status of specimens used for breeding stock we refer to this species as *H. sinuata* Mulsant sensu latu in this article.

Few studies have addressed *H. sinuata* biology. Hagen & Sluss (1966) evaluated *H. s. sinuata*, *H. convergens*, and *H. quinquesignata punctulata* LeConte adults fed on the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), for oviposition. *H. sinuata* had a preovipositional period ranging from 4.4 to 9.2 d and consumed 304–669 aphids during this period, depending on the number of generations after overwintering emergence. Smith & Hagen (1966) studied the seasonal distribution of *H. sinuata* along with other coccinellid species in alfalfa infested with the spotted alfalfa aphid in California.

Because *H. sinuata* predation is an important facet of the naturally occurring biological control of greenbugs in the Texas High Plains, we conducted laboratory studies to determine the effects of temperature and aphid prey species on the growth and development of this beetle. The corn leaf aphid, *Rhopalosiphum maidis* (Fitch), was included as a separate prey species because it is a very abundant aphid species on grain sorghum early in the growing season, and personal observations indicate that *H. sinuata* readily feeds on this species.

Materials and Methods

All studies were carried out at the Texas Agricultural Experiment Station, Texas A&M University, Research and Extension Center at Amarillo–Bushland, Tex.

Large numbers of *H. sinuata* adults were collected from greenbug-infested sorghum at Bushland, Tex., and brought to the laboratory to establish a founder colony. The sex of the adults was determined, and five pairs of adults were placed in plastic Petri dishes and supplied with an overabundance of either greenbugs or corn leaf aphids on a daily basis, depending on the particular study for which they were to be used. The adults were kept in Percival I30BLL desktop incubators at the same temperature at which larval development would be observed. At 48 h, males were removed from the Petri dishes to preclude egg cannibalism. When a sufficient number of eggs were laid, the female was removed and the eggs were monitored

Table 1. Mean duration (±SD) of immature stages of *H. sinuata* reared on two aphid species at constant temperatures

Stage[a]	Temp, °C					
	10	15	20	25	30	35
			R. maidis			
Egg	11.6 (2.0)a	9.6 (4.0)b	5.7 (1.0)c*	2.0 (0.0)d	2.5 (0.5)d*	2.0 (0.0)e
I1	13.0 (6.0)a	11.9 (5.4)a*	2.0 (0.2)b*	3.5 (0.5)b	2.0 (0.2)b*	2.0 (0.4)b
I2	15.8 (17.0)a	9.9 (4.7)a	3.0 (1.2)b	2.3 (1.3)b*	1.0 (0.0)b	1.1 (0.5)b
I3	12.5 (16.0)a	11.4 (5.0)a	2.5 (1.2)b*	2.3 (1.2)b	1.9 (0.3)b	1.7 (0.6)b*
I4	5.7 (12.5)a	8.6 (5.9)a	2.4 (1.0)ab*	2.4 (1.3)ab	3.0 (0.5)ab*	1.4 (0.6)b*
Prepupa	died	2.8 (1.5)a	2.0 (0.9)a	0.8 (0.3)b	0.9 (0.5)b	0.8 (0.9)b
Pupa		10.8 (5.6)c	4.1 (1.9)a*	4.9 (1.9)a	2.4 (0.5)b	3.2 (1.6)ab
Total	—	65.1 (6.8)a	21.8 (5.1)b*	18.2 (3.6)bc	13.7 (0.8)c	12.2 (2.9)c
			S. graminum			
Egg	nd[b]	10.6 (0.5)a	4.5 (0.5)b*	2.0 (0.0)d	3.0 (0.2)c*	2.0 (0.0)d
I1		16.9 (3.5)a*	5.1 (0.7)b*	3.3 (0.5)c	2.3 (0.5)d*	2.1 (0.3)d
I2		2.2 (6.1)ab	3.6 (1.1)a	1.6 (0.6)b*	1.0 (0.5)b	1.0 (0.2)b
I3		died	3.4 (1.0)a*	2.1 (0.6)b	1.8 (1.0)b	2.0 (0.5)b*
I4			4.8 (3.2)a*	2.4 (0.8)b	1.9 (1.0)b*	1.8 (0.4)b*
Prepupa			1.6 (8.8)a	0.9 (0.3)b	0.8 (0.4)b	0.8 (0.4)b
Pupa			5.6 (4.8)a*	6.0 (1.9)a	2.0 (1.1)c	3.3 (0.5)b
Total	—	—	28.7 (5.8)a*	18.4 (3.4)b	12.8 (3.0)c	13.1 (0.3)c

Means in a row followed by the same letter are not significantly different ($P > 0.05$, Student–Newman–Keuls). Means in a column followed by an asterisk are significantly different between prey species ($P > 0.05$, Student–Newman–Keuls).
[a] I1–I4 indicate instars 1–4, 25 replications per prey species per temperature regime.
[b] nd, no development.

daily for eclosion. Corn leaf aphid and greenbug colonies were reared on sorghum in the greenhouse. Voucher specimens of *H. sinuata* and the aphid prey were placed in the insect collection at the Texas Agricultural Experiment Station at Bushland, Tex.

Twenty-five neonate larvae, randomly selected from egg masses of different females, were sequestered individually into 30-ml plastic condiment cups with paper lids. Each larva was considered as a replication. The larvae were placed at either 10, 15, 20, 25, 30, or 35°C with a 16:8 (L:D) photoperiod. A known number of the appropriate aphid species was added to each cup on a daily basis. This number ranged from 5 to 50 aphids, to guarantee an overabundance of prey as the larvae progressed through the various instars. Aphid prey consisted of a mixture of second through fourth instars and adults. *H. sinuata* larvae were examined daily for molting. The remaining aphids were counted and removed, along with exuviae if present, and fresh aphids were added.

Statistical treatment of the data consisted of first analyzing the experiment as a factorial design using the general linear model procedures available in the Statistical Analysis System for Personal Computers (SAS Institute 1988). The model for the first analyses followed the form:

OBSERVED = TEMPERATURE + PREY SPECIES + (TEMPERATURE × PREY SPECIES),

where OBSERVED was set equal to development time in days for immature stage, the total immature duration, the total number of aphids consumed, and the aphids consumed per day for each immature stage. Because the temperature × prey species term was significant, the data were analyzed as one-way analyses of variance for each temperature over prey species and for each prey species over temperature. Significant means were separated using the Student–Newman–Keuls test ($P > 0.05$).

To describe the relationship between development rate, temperature, and prey species, we calculated developmental rate curves for each prey regime over temperatures as linear regressions using the formula:

$$1/\text{DAYS} = b_1 + (b_0 \times \text{TEMPERATURE}).$$

Two empirical values were derived from the development velocity curves: t, the lower theoretical temperature threshold for development, estimated as the x-intercept ($-b_1/b_0$) from an extrapolation of the regression; and K, the number of degree-days above t needed for development, estimated as the inverse of the slope of the regression ($1/b_0$).

Table 2. Comparison of *H. sinuata* threshold temperatures (t) and developmental degree-days (K) to other *Hippodamia* species

Species	Prey species	t	K
H. sinuata	*R. maidis*	7.05	338.63
H. convergens	*A. gossypii/M. persicae*	10.60	313.20[a]
H. parenthesis	*Acyrthosiphon pisum*	10.80	234.80[b]
H. convergens	*A. pisum/M. persicae*	12.00	230.30[a]
H. sinuata	*S. graminum*	12.90	259.54
H. variegata	*S. graminum*	17.19	129.00[c]

[a] Obrycki & Tauber 1982.
[b] Orr & Obrycki 1990.
[c] Michels & Bateman 1986.

Results and Discussion

Development. The development times for each temperature–prey combination are found in Table 1. At 10°C, *H. sinuata* failed to complete development when fed corn leaf aphids. The larvae progressed through four instars, but never pupated. The same results were found when the larvae were fed greenbugs at 15°C. In this case, the larvae failed to develop past the second instar. In general, when development to the adult was observed, *H. sinuata* developed more rapidly as temperatures increased, regardless of the prey species. *H. sinuata* developed significantly faster on corn leaf aphids than on greenbugs at 20°C. At this temperature regime, the larvae fed corn leaf aphids completed their development to adults ≈7 d earlier than those fed greenbugs. At the other temperature regimes, the number of days required to complete development was very similar, differing by no more than 0.9 d.

The estimates of t and K (Table 2 and Fig. 1) indicate that *H. sinuata* should begin development at a lower threshold temperature when fed on corn leaf aphids as opposed to greenbugs (7.05 and 12.90 for corn leaf aphid and greenbug, respectively). More degree-days above the threshold temperature are necessary to complete development on corn leaf aphids (338.63) compared with greenbugs (259.54).

As with other *Hippodamia* species (Table 2), *H. sinuata* is apparently quite variable in regard to t and K estimates, depending on prey species. In studies by other researchers on *Hippodamia* species, the lowest t was reported by Obrycki & Tauber (1982) for an Arizona population of *H. convergens* fed a combination diet of *Aphis gossypii* and *Myzus persicae*. The highest t was reported by Michels & Bateman (1986) for *H. variegata*, an imported species from South Africa.

Aphid Consumption. The total number of aphids consumed by *H. sinuata* during the immature stages is presented in Table 3. *H. sinuata* reared on corn leaf aphids consumed the largest number of aphids at 25°C. This was a significantly greater number of aphids than that consumed by beetles reared at 15 or 35°C, but not significantly different than those

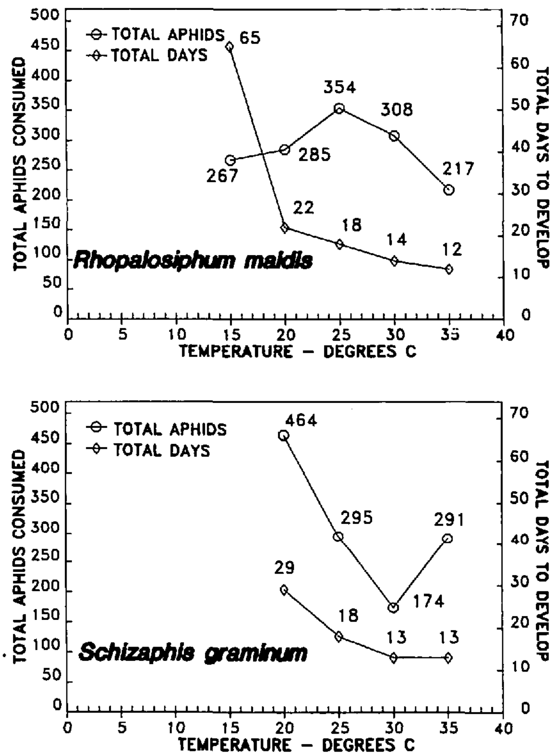

Fig. 1. Developmental rate curves for *H. sinuata* when fed corn leaf aphid, *R. maidis*, and greenbug, *S. graminum*. For corn leaf aphid, $y = -0.0208 + 0.0030x$, $r^2 = 0.90$. For greenbug, $y = -0.0497 + 0.0039x$, $r^2 = 0.92$.

Table 3. Mean total aphids (±SD) consumed by *H. sinuata* larvae reared on two aphid species at constant temperatures

Stage[a]	Temp, °C					
	10	15	20	25	30	35
			R. maidis			
I1	55.4 (21.7)a	63.4 (43.8)a*	8.5 (2.9)c*	20.7 (5.5)b	9.5 (2.0)bc	7.6 (3.1)c
I2	82.2 (81.9)a	52.4 (60.9)b	43.8 (26.8)bc	58.1 (48.4)ab*	20.2 (3.2)c	18.8 (11.9)c
I3	71.4 (89.7)a	81.6 (96.3)a	77.0 (41.1)a	91.8 (43.5)a*	74.1 (15.5)a*	65.2 (22.8)a
I4	31.0 (66.3)c	69.6 (105.9)c	155.6 (66.2)ab*	183.4 (83.0)a	195.8 (35.5)a*	125.6 (46.0)b*
Total	240.0 (124.4)bc	267.0 (208.7)bc	285.0 (107.3)abc*	354.0 (84.7)a*	308.0 (32.2)ab*	217.2 (69.3)c*
			S. graminum			
I1	nd[b]	117.4 (27.5)a*	42.0 (10.0)b*	17.6 (6.2)c	9.9 (7.8)cd	8.9 (3.5)d
I2		24.9 (69.3)b	44.4 (17.4)a	27.8 (9.4)ab*	13.0 (11.2)b	17.0 (4.9)b
I3		0.0 (0.0)d	96.8 (44.4)a	66.0 (23.1)b*	48.2 (27.1)c*	76.2 (23.3)b
I4		died	280.9 (107.0)a*	183.8 (51.0)b	102.7 (52.2)c*	188.8 (36.6)b*
Total	—	—	464.1 (140.1)a*	295.3 (65.6)b*	173.8 (65.3)c*	290.8 (33.8)b*

Means in a row followed by the same letter are not significantly different ($P > 0.05$, Student–Newman–Keuls). Means in a column followed by an asterisk are significantly different between prey species ($P > 0.05$, Student–Newman–Keuls).

[a] I1–I4 indicate instars 1–4, 25 replications per prey species per temperature regime.

[b] nd, no development.

reared at 20 or 30°C. Beetles that fed on greenbugs consumed significantly more aphids at 20°C and significantly fewer aphids at 30°C than those reared at 25 and 35°C.

A comparison of the total aphids consumed and the total days for the beetle larvae to develop, by prey species, is illustrated in Fig. 2. When corn leaf aphids were used as prey, total aphid consumption rose from 267 at 15°C to a maximum of 354 at 25°C, and then fell to a low of 217 at 35°C. However, development decreased for each increment in temperature. When beetles were fed on greenbugs, the opposite trend was found. *H. sinuata* total development time and aphid consumption followed a generally similar trend, with totals dropping as temperatures increased. An exception was found at 35°C, where aphid totals rose significantly and the total days to development leveled off. This trend is also found on an instar-by-instar basis (Table 3). When aphid consumption data are compared between prey species at 20 and 35°C, *H. sinuata* larvae consumed significantly more greenbugs than corn leaf aphids before completing development. The reverse was true for 25 and 30°C.

Because the beetles were always supplied with an overabundance of aphids, it is difficult to say whether these figures represent empirical totals needed for development. Difficulties that beetles would have in searching for prey were not accounted for in this study. Beetles reared at lower temperatures may have been affected by a lower metabolism, whereas those at higher temperatures were probably functioning at a higher metabolic rate. In addition, the nutritional quality of aphids may have changed at higher or lower temperatures, which could have affected beetle development.

Daily aphid consumption (Table 4) reflected results similar to the total number of aphids consumed during the larval stages, when compared between prey species at a specific temperature.

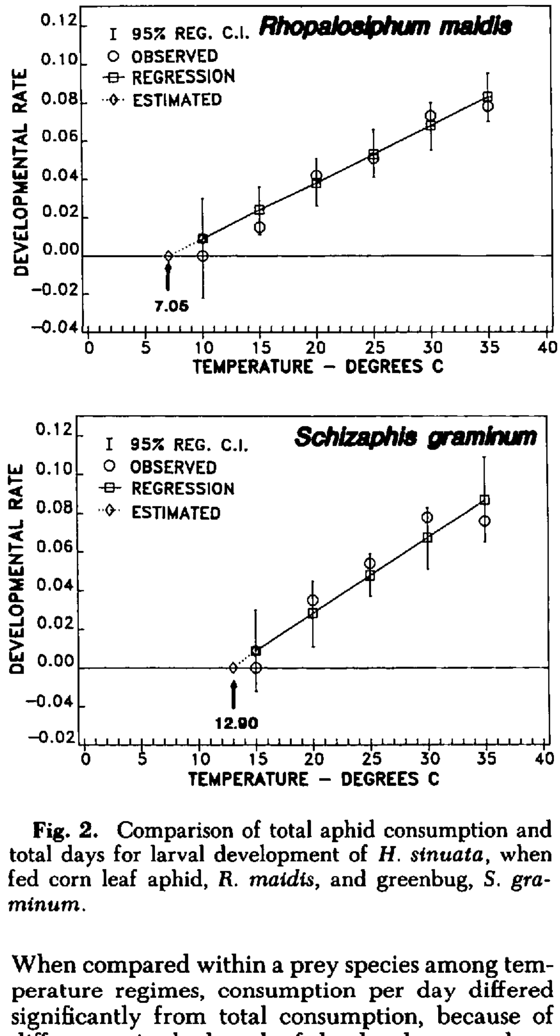

Fig. 2. Comparison of total aphid consumption and total days for larval development of *H. sinuata*, when fed corn leaf aphid, *R. maidis*, and greenbug, *S. graminum*.

When compared within a prey species among temperature regimes, consumption per day differed significantly from total consumption, because of differences in the length of the developmental period. Beetles fed corn leaf aphids and reared at 30°C consumed an average of 22.5 aphids per day,

Table 4. Mean daily consumption (±SD) of two aphid species by *H. sinuata* larvae reared at constant temperatures

Stage[a]	Temp, °C					
	10	15	20	25	30	35
			R. maidis			
I1	4.4 (0.8)cd	5.2 (2.2)ab*	4.2 (1.3)cd*	5.9 (0.8)a	4.8 (1.0)bc	3.8 (1.1)d
I2	4.7 (2.6)c	6.2 (2.6)c*	13.7 (5.4)b	20.5 (9.3)a	20.2 (3.2)a*	15.5 (5.8)b
I3	2.5 (3.0)c	7.7 (2.3)c	27.8 (13.2)b	41.6 (16.1)a*	38.2 (4.7)a*	36.3 (11.5)a
I4	0.3 (0.8)d	4.1 (2.6)c	16.2 (15.2)b	31.2 (29.2)a	6.9 (1.8)c	13.1 (7.2)b
Total	3.8 (1.1)d	7.4 (0.8)d	12.5 (3.9)c*	19.0 (3.8)b*	22.5 (2.2)a*	17.2 (5.7)b*
			S. graminum			
I1	nd[b]	6.9 (0.5)b*	8.1 (1.0)a*	5.2 (1.1)c	4.1 (2.9)d	4.2 (3.5)d
I2		1.4 (3.8)c*	11.9 (3.2)b	16.5 (3.8)a	10.4 (5.8)b*	16.2 (4.9)a
I3		died	25.8 (8.8)bc	29.6 (7.0)b*	23.7 (10.0)c*	37.1 (23.3)a
I4		—	9.0 (4.8)b	12.4 (6.6)b	7.1 (8.8)c	10.2 (33.8)a
Total		—	15.7 (4.0)b*	15.7 (2.8)b*	13.0 (3.8)c*	22.2 (2.6)a*

Means in a row followed by the same letter are not significantly different ($P > 0.05$, Student–Newman–Keuls). Means in a column followed by an asterisk are significantly different between prey species ($P > 0.05$, Student–Newman–Keuls).

[a] I1–I4 indicate instars 1–4, 25 replications per prey species per temperature regime.

[b] nd, no development.

which was significantly higher than those reared at 25 and 35°C. The latter consumed significantly more than beetles reared at 20°C. Those beetles reared at 15°C consumed significantly fewer aphids than at any other temperature regime.

Greenbug-fed beetles consumed an average of 22 aphids per day at 35°C, which was significantly higher than at all other temperatures. Beetles reared on greenbugs at 20 and 25°C consumed significantly more than those reared at 30°C.

Conclusions. Immature development of *H. sinuata* on either corn leaf aphids or greenbugs was dependent on temperature. Development could not be completed on corn leaf aphids below 15°C or on greenbugs below 20°C. At 20°C, *H. sinuata* development was significantly faster on corn leaf aphids than on greenbugs. At temperatures >20°C, development was not significantly different between prey species. Optimal prey consumption was observed at 30°C (22.5 aphids/d) for larvae feeding on corn leaf aphids, and at 35°C (22.2 aphids/d) for larvae feeding on greenbugs.

Estimates of the thermal threshold for development and the number of degree days over the threshold for development indicated that *H. sinuata* should begin development at a lower thermal threshold when fed corn leaf aphids as opposed to greenbugs, but they will require more degree days to complete development.

The results of our studies point to the importance of corn leaf aphid as a food source for *H. sinuata* in the field. Because corn leaf aphid is usually the first aphid to appear on grain sorghum in the early summer (G.J.M., unpublished data), it can provide an initial "boost" to the development of *H. sinuata* populations in the field, which would then be present when greenbug densities begin to increase.

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