

## Effects of temperature on survival and preimaginal development rates of Colorado potato beetle on potato and horse-nettle: potential role in host range expansion

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### Abstract

The effect of temperature on the ability of Colorado potato beetles (*Leptinotarsa decemlineata*, Say) to use horse-nettle (*Solanum carolinense* L.) as a host plant was determined for larvae from colonies originating from two geographically separated populations, one adapted to horse-nettle (NC) and the other unadapted to horse-nettle (MA). Survival and developmental rate on horse-nettle and potato were measured for larvae from both colonies over a range of constant temperatures (12–30 °C) and one fluctuating temperature regime (22 °C to 30 °C). The ability of Colorado potato beetles to use horse-nettle as a larval host was strongly influenced by temperature, but the effects of temperature differed greatly between beetles from the two colonies. Survival of adapted larvae on horse-nettle was highest and comparable to that on potato at the constant 30 °C and the fluctuating temperature regime. Below 30 °C, survival of adapted larvae decreased drastically but some larvae survived at all temperatures except the lowest (12 °C). In contrast, survival of unadapted larvae to adult occurred only at 30 °C, and was low (10%). At lower temperatures, all larvae died. On potato, the effect of temperature was less dramatic, and consistent across colonies. At 12 °C, survival to adult was poor (ca. 10%), but at higher temperatures, survival increased sharply and larvae from both colonies survived equally well. On potato, small but statistically significant differences in developmental rates between beetle colonies were detected at the constant but not at the fluctuating temperature regimes. Also, the developmental day degree requirements (DD) and the low temperature development threshold (T<sub>0</sub>) values for the various developmental stages did not differ between colonies on potato. On horse-nettle, development times for both colonies were always significantly longer and DD requirements were greater than on potato. At 30 °C, the only constant temperature at which larvae from the unadapted colony completed development, the development rate to adult emergence was similar to that of beetles from the adapted colony. Differences between colonies in performance on horse-nettle were not a result of host-independent, genetically based differences in the thermal requirements of the two populations. Our findings are consistent with the hypothesis that adaptation to horse-nettle by Colorado potato beetle may be facilitated by a genotype × environment interaction involving temperature. These findings have important implications for host plant utilization, host range expansion and selection of pest biotypes adapted to plant resistance traits used in crop protection.

### Introduction

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say), has a host range that includes approximately 20 species in the family Solanaceae (Hsiao,

1978), although considerable differences in the ability to utilize specific plant species as hosts exist among populations of Colorado potato beetle (Hsiao, 1978; de Wilde & Hsiao, 1981; Hsiao, 1982; Hare & Kennedy, 1986; Harrison, 1987; Kennedy & Farrar,

1987; Horton et al., 1988; Pelletier & Smilowitz, 1991; Franca et al., 1994; Lu & Logan, 1994a, b; Lu et al., 1997). These differences are affected by genetic and ecological factors which include both within and among population genetic variation in the ability to use specific plant species as hosts, and the availability and predictable occurrence of alternate host species (Hsiao, 1978; Hare & Kennedy, 1986; Horton et al., 1988; Via, 1990). Environmental factors may also influence a plant's attractiveness and suitability as a host or the insects response to the host (de Wilde et al., 1969; Tingey & Singh, 1980; Heinrichs, 1988; Barbour et al., 1991).

Horse-nettle, *Solanum carolinense* L., is native to the Gulf Coast region of the US, but has spread north into southern Canada, where it was first reported in 1891, and west into California (Bassett & Munro, 1986). Hare & Kennedy (1986) documented that a Colorado potato beetle population from North Carolina was better adapted to use horse-nettle as a host plant than populations in Virginia, Connecticut and New Jersey. They further demonstrated that the differences were genetically based and that the ability of the North Carolina population to use horse-nettle as a host was not accompanied by a decline in ability to use potato as a host. Thus, adaptation to horse-nettle as a host represented an expansion rather than a shift in host range (Hare, 1990). Other examples of host range expansions by the Colorado potato beetle are described by Hsiao (1978), Horton et al. (1988), and Lu et al. (1997). Hare & Kennedy (1986) hypothesized that adaptation to horse-nettle by the North Carolina population was the result of intense selection imposed by the removal of potato plants from the agroecosystem early in the season due to potato harvest in June (see also Kennedy, 1993). The occurrence of a horse-nettle adapted potato beetle population at a site in southwestern Michigan where potatoes have not been grown for approximately 40 years is consistent with this hypothesis (Mena-Covarrubias et al., 1996).

Temperature has been shown to influence host selection by Colorado potato beetle in at least some situations. When given a choice between potato and *Solanum dulcamara*, Colorado potato beetles chose potato more frequently at low temperatures and *S. dulcamara* at high temperatures (de Wilde et al., 1969). Thus, patterns of host plant utilization observed in a particular locality may be influenced by temperature. This study was undertaken to determine if temperature influences the ability of Colorado potato beetle to utilize horse-nettle as a larval host, and if temperature

differentially affects development rate and survival on horse-nettle of larvae from horse-nettle adapted and unadapted populations.

## Materials and methods

**Insects.** Colorado potato beetles used in these experiments were from two laboratory colonies representing geographically separated populations. One, designated MA, was started with adult beetles collected from potato in Massachusetts by D. N. Ferro (Department of Entomology, University of Massachusetts). The other, designated NC, was started from adults collected from potato in Washington County, North Carolina. At least 50 individuals were used to initiate each colony. The colonies had been maintained for 3 generations or less on potato (*Solanum tuberosum* L.) in the greenhouse when we began the experiment to measure survival and development rates on potato and horse-nettle (*S. carolinense* L.) under different temperature regimes.

**Experimental conditions.** The experiment was carried out in 6 controlled environment chambers housed in the Southeastern Plant Environmental Laboratory (Phytotron) at North Carolina State University. Each chamber was set to one of 5 constant temperatures (12, 17, 22, 27, or 30 °C). In addition, one chamber was set to a variable regime in which the temperature was 30 °C during the first 8 h of the 14 h photophase and 22 °C during the remainder of the photophase and throughout the 10 h scotophase. The average temperature in this variable temperature regime was 25 °C. Temperatures were controlled to  $\pm 0.5$  °C about the set points. Lighting was provided by power groove, 1500 ma, cool-white fluorescent and incandescent lamps. Relative humidity in the chambers fluctuated between 50 and 70%.

Prior to their placement in environmental chambers, experimental plants were grown in a greenhouse in which 1200 W, mixed-metal, halide lamps augmented natural day length to a minimum of 14 h, and temperatures were maintained between 18 and 27 °C. They were grown in 15 cm clay pots using Metromix 200® standard potting substrate. Potato plants (variety 'Atlantic') were grown from certified seed tubers. Horse-nettle plants were grown from field-collected root stocks. At the start of the experiment, potato and horse-nettle plants were 4 and 6 weeks old, respectively. Throughout the experiment, plants in the

environmental chambers were replaced as necessary to maintain an adequate supply of foliage to developing insects.

**Experimental procedures.** Within each of the six temperature regimes, each potato beetle colony  $\times$  host plant combination represented one treatment and was replicated four times in a  $2 \times 2$  factorial design. Each potted plant was infested with 10 first instar larvae and represented one replication. This resulted in 40 first instar larvae per colony  $\times$  host plant treatment, and a total of 160 first instar per temperature regime.

To initiate the experiment, 20 egg masses, none more than 24 h old, were collected from each colony and the excess foliage around each egg mass removed. The egg masses were then placed in 9 cm petri dishes and incubated at the various temperature regimes. They were checked twice daily until hatch. After the neonates had dispersed from their egg mass, they were transferred to their assigned host plant treatment. Larvae were confined in pairs on foliage of their host plants by enclosing them in leaf cages constructed from modified 5.5 cm plastic petri dishes and nylon organza screen. In addition, each plant was covered with a loose-fitting nylon screen cage, the bottom of which was sealed to the upper lip of the clay pot. When the larvae reached the last instar (fourth instar), they were released from the leaf cages and allowed free access to the remainder of the plant and the soil to complete their development and pupate. Adult emergence was recorded to provide data on overall survival rates and development times (egg hatch to adult).

Survival, development, and adult emergence were monitored every second day at the lowest temperature (12 °C), and daily at all other temperatures. Development times for egg masses were added to development times for the larval and pupal stages within the same temperature regimes to obtain total development times.

Survival values for the combined first and second instars (small larvae) and the combined third and fourth instars (large larvae) on each plant were calculated as the number of individuals completing the combined stage divided by the number of individuals entering the stage. Survival data were arcsine transformed prior to statistical analysis.

**Statistics.** Treatment effects on survival and development rate (1/development time in days) were analyzed using the GLM procedure of SAS (SAS Institute, 1988). The ANOVA model partitioned treatment

effects into main effects (temperature, colony, and host) and interaction effects. The temperature main effect for development was further partitioned into a linear ( $T$ ) and a quadratic ( $T * T$ ) component. Statistical analyses on the complete data set were performed to test for differences between host plants and colonies, and for main factor interactions. If 3-way interactions (temp $\times$ host $\times$ colony) were significant, separate analyses were conducted for each host plant (host specific analyses). Probability levels are reported for all significant effects. All effects reported as nonsignificant had levels of  $P > 0.1$ .

Because high mortality among third and fourth instars from the MA colony on the horse-nettle treatments resulted in many missing values, particularly at lower temperatures, development rate data for these stages and for development from first instar through adult were subjected to analysis of variance only at the 30 °C temperature regime. Host specific analyses of these data were conducted only if the colony  $\times$  host interaction was significant.

Stage specific lower thermal threshold values ( $T_0$ ) for development were estimated by extrapolation through the  $x$ -axis (temperature) of a regression performed on the linear portion of the temperature response curve of development rate. The estimated  $T_0$  values were analyzed statistically for significant treatment differences. Because no significant treatment differences were detected, an average  $T_0$  value (9.3 °C) was used for calculating developmental degree-days (DD). Stage-specific DD were calculated from the equation  $DD = d(T - T_0)$ , where  $d$  is the number of days required to complete a given developmental stage and  $T$  is the mean daily temperature. Resulting DD values were analyzed statistically for significant treatment differences using the ANOVA procedure of SAS (SAS Institute, 1988). Because of missing values, DD and  $T_0$  values for MA larvae on horse-nettle were not calculated.

## Results

**Survival at constant temperatures.** Survival of small (combined first and second instars) larvae was affected by temperature ( $P = 0.0001$ ), host plant ( $P = 0.0001$ ) and the temperature  $\times$  host plant interaction ( $P = 0.0001$ ). Neither the main effect of colony, nor the 2-way interactions involving colony, nor the temperature  $\times$  colony  $\times$  host plant interaction were significant, indicating that the individual and com-

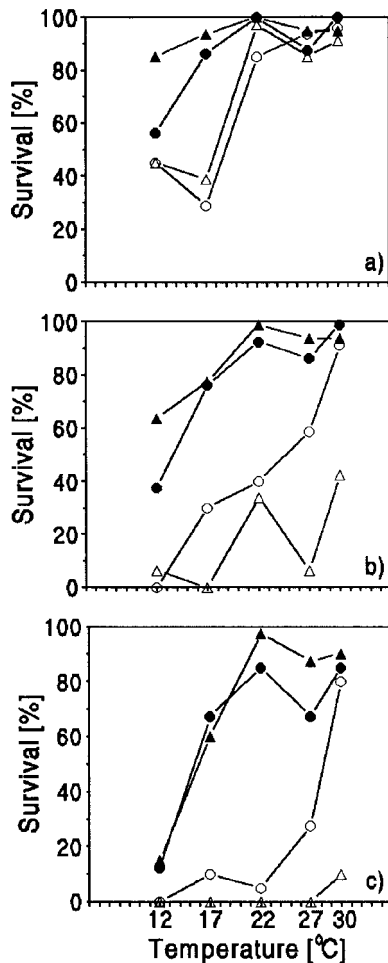


Figure 1. Stage specific survival of Colorado potato beetles from NC and MA colonies when reared on potato and horse-nettle under constant temperature regimes: (a) small larvae (first and second instars), (b) large larvae (third and fourth instars), (c) total preimaginal life (L1 through A), (● North Carolina (NC) on potato, ▲ Massachusetts (MA) on potato, ○ North Carolina (NC) on horse-nettle, △ Massachusetts (MA) on horse-nettle).

bined effects of temperature and host plant on survival of small larvae were similar for both colonies. Survival of both NC and MA small larvae was higher on potato than horse-nettle at temperatures below 22 °C but comparable on the two hosts at higher temperatures (Figure 1a).

Survival of large (combined third and fourth instars) larvae was influenced by a significant temperature  $\times$  colony  $\times$  host plant interaction ( $P = 0.0001$ ), indicating that the response to the combined effects of temperature and host plant differed between colonies. As with small larvae, survival of large larvae on potato tended to be higher than on horse-nettle

for larvae from both colonies at all temperatures except 30 °C. At 30 °C, survival of NC but not MA large larvae on horse-nettle was comparable to that on potato (Figure 1b). Separate host specific analyses of large larval survival revealed significant temperature  $\times$  colony interactions on both potato and horse-nettle ( $P = 0.0001$ ). On potato, the interaction resulted from higher survival of MA than NC larvae at 12 °C and the generally similar survival of larvae from both colonies at higher temperatures. On horse-nettle, the interaction was due to a general increase in survival with increasing temperature, ranging from 0% survival at 12 °C to 90% survival at 30 °C, among NC larvae and a highly variable response to increasing temperature among MA larvae (Figure 1b).

Survival from first to adult was similarly affected by an interaction of temperature  $\times$  colony  $\times$  host ( $P = 0.0001$ ). Survival to adult was lower on horse-nettle than on potato at all temperatures except 30 °C where survival of NC beetles was comparable to that of both NC and MA beetles on potato, but significantly greater than that of MA beetles on horse-nettle ( $P = 0.0001$ ; Figure 1c). Host specific analysis on potato revealed only a significant main effect of temperature on survival ( $P = 0.0001$ ). A similar analysis on horse-nettle revealed a significant temperature  $\times$  colony interaction ( $P = 0.0001$ ). This interaction is explained by the fact that some MA beetles survived to adult on horse-nettle only at 30 °C, whereas some NC beetles survived on horse-nettle at all temperatures above 12 °C, and their survival rate increased with increasing temperature between 22 and 30 °C.

Together these results reveal that survival of potato beetle larvae increased with temperature between 12 and 30 °C but the response to temperature was affected by host plant and differed between beetles originating from the MA and NC colonies.

**Survival at fluctuating temperatures.** Survival of first and second instars at the fluctuating temperature regime (mean temperature = 25 °C) was high and unaffected by colony or host plant, or by the colony  $\times$  host plant interaction (Figure 2a). However, the colony  $\times$  host plant interactions were significant for survival of third and fourth instars ( $P = 0.01$ ), as well as for survival from first instar to adult ( $P = 0.001$ ). Specifically, survival of third and fourth instars from both colonies was 100% on potato, but on horse-nettle it was lower for larvae from the MA than the NC colony (Figure 2b). Survival from first instar to adult was high and generally similar on potato for MA and NC larvae,

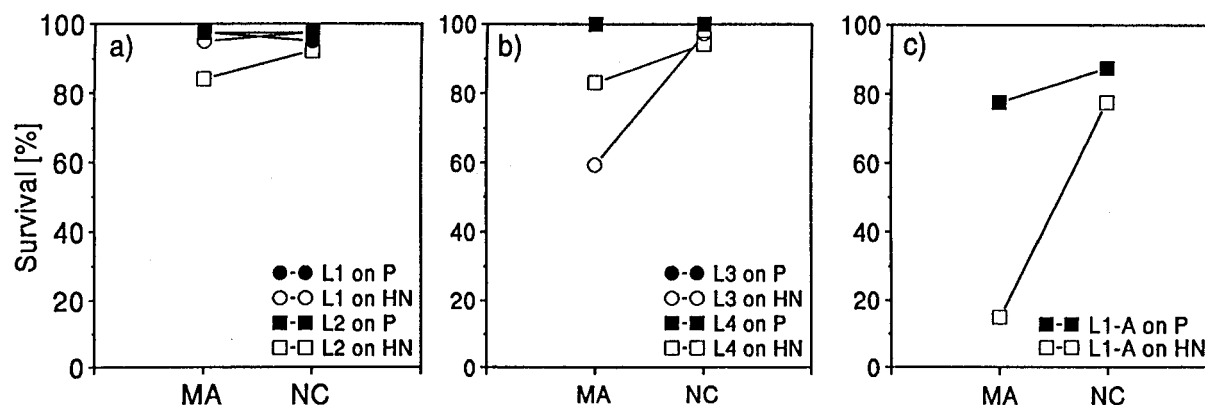


Figure 2. Fluctuating temperature regime (average temperature = 25 °C): Interaction plots of stage-specific survival for first (L1), second (L2), third (L3) and fourth (L4) instars, and total preimaginal life (L1 through A) for all Colorado potato beetle colony by host plant combinations (P = potato; HN = horse-nettle; MA = Massachusetts; NC = North Carolina).

but differed greatly between colonies on horse-nettle (Figure 2c), as was the case at the 30 °C constant temperature regime (Figure 1c). Under the fluctuating temperature regime, 15% of the MA larvae and 78% of the NC larvae survived to adult on horse-nettle, as compared to 10% and 80% survival of MA and NC larvae, respectively under the 30 °C constant temperature regime.

**Development rates at constant temperatures.** The development rates of eggs were similar for both the NC and MA colonies, and increased linearly with increasing temperature (Figure 3a). Eggs from NC and MA beetles required 63 and 69 DD, respectively, to complete development (Table 1).

Development rates of first instars increased linearly with temperature up to 22 °C, but did not increase further with increasing temperature. This resulted in significant linear ( $P = 0.0001$ ) and quadratic responses ( $P = 0.0001$ ) to temperature (Figure 3b). In contrast, the development rates of second instars increased linearly with temperature up to 30 °C ( $P = 0.0001$ ; Figure 3c).

Development rates of both first and second instars from both colonies were generally lower on horse-nettle than on potato (Figures 3b and 3c). However, there was a significant colony  $\times$  host interaction for first instars ( $P = 0.008$ ), which appears to be due to the slightly higher development rate of MA first instars than NC first instars on potato and the slightly lower development rate of MA first instars than NC first instars on horse-nettle. There was also a significant temperature (quadratic)  $\times$  colony interaction effect due to a slight increase in the development rate

of MA first instars on both hosts and a slight decrease in the development rate of NC larvae on both hosts between 27 and 30 °C. For both MA and NC second instars, a proportionally greater increase in development rate on potato between 27 and 30 °C resulted in a significant temperature (linear)  $\times$  host interaction effect ( $P = 0.0027$ ).

Although not subjected to statistical analyses over the full range of temperature treatments due to poor larval survival at some temperatures, development rates during the third and fourth instars generally increased with temperature at least up to 27 °C (Figure 3d and e). Analysis of variance of data on development rates for third instars at 30 °C revealed a significant effect of host plant ( $P = 0.0001$ ) but not of colony or of colony  $\times$  host interaction. Thus, third instars from both colonies developed more rapidly on potato than horse-nettle (Figure 3d). The development rates for 4th instars at 30 °C were also lower on horse-nettle than potato ( $P = 0.0001$ ) but were influenced by a significant colony  $\times$  host interaction ( $P = 0.005$ ). Host specific analyses revealed this to be due to a significantly higher development rate of MA than NC fourth instars on potato ( $P = 0.03$ ) and a higher development rate of NC than MA fourth instars on horse-nettle ( $P > 0.056$ ).

Development rates from first instar to adult increased with temperature between 12 and 30 °C for NC beetles on potato and horse-nettle, and for MA beetles on potato. MA beetles survived to adult on horse-nettle only at 30 °C. Analysis of development rates at 30 °C revealed a significant effect of host plant ( $P = 0.0043$ ) but not of colony or of colony  $\times$  host interaction (Figure 3f). Thus, beetles from both colonies

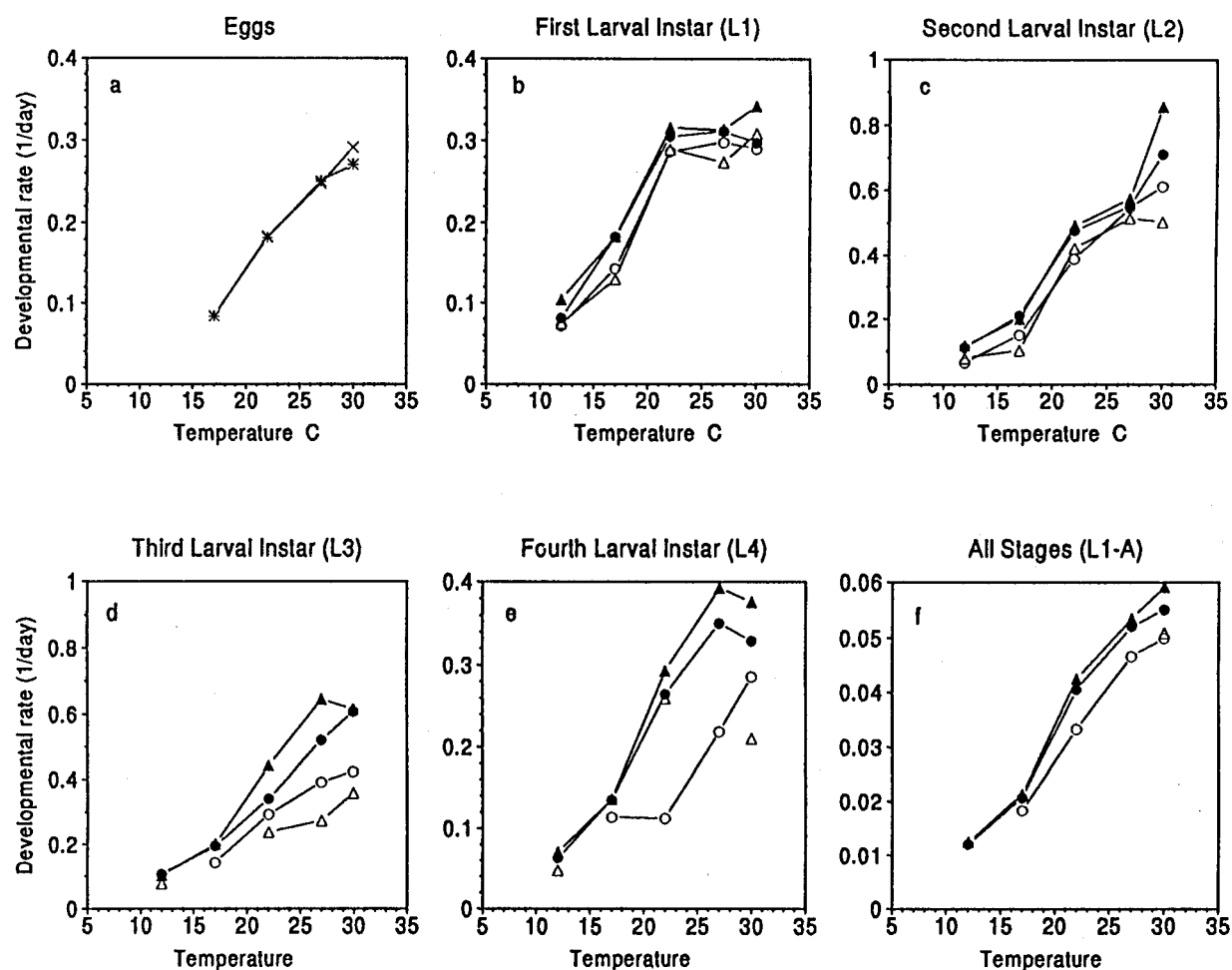


Figure 3. Stage specific development rates of Colorado potato beetles from NC and MA colonies when reared on potato and horse-nettle under constant temperature regimes: (a) eggs, (b) first instars (L1), (c) second instars (L2), (d) third instars (L3), (e) fourth instars (L4), and (f) total preimaginal life (L1 through A), (● North Carolina (NC) on potato, ▲ Massachusetts (MA) on potato, ○ North Carolina (NC) on horse-nettle, △ Massachusetts (MA) on horse-nettle).

completed development to adult at 30 °C faster on potato than on horse-nettle, but on each host surviving beetles from both the NC and MA colonies developed at comparable rates.

The DD requirements for first and second instars from both colonies were similar on potato, but both the first and second instar NC larvae had a significantly higher DD requirement on horse-nettle than on potato (Table 1). The  $T_0$  values did not differ significantly between colonies and host plants, and ranged from 7.56 to 10.32 °C.

The DD requirements for NC third and fourth instars on horse-nettle were significantly greater than those for both NC and MA larvae on potato (Table 1). However, on potato, the DD requirements differed

significantly between NC and MA larvae in the third instar but not in the fourth instar (Table 1). The  $T_0$  values ranged among the treatments from 7.8 to 11.6 °C, but did not differ significantly.

NC larvae on horse-nettle required 233 DD to complete larval development and 515 DD to develop from egg to adult. On potato, NC and MA larvae required 162 and 150 DD, respectively, to complete larval development, and 427 and 426 DD, respectively, to complete development from egg to adult (Table 1).

*Development rates at fluctuating temperatures.* The colony by host interaction effects on development rate were significant for second ( $P = 0.0037$ ), third ( $P = 0.0012$ ), and fourth instars ( $P = 0.0043$ ) and for de-

Table 1. Stage-specific degree day requirements (DD) and lower thermal threshold values ( $T_0$ ) for the Colorado potato beetle populations from North Carolina (NC) and Massachusetts (MA)

Dev. stage	NC Population						MA Population		
	Potato			Horse-nettle			Potato		
	N	DD	$T_0$	N	DD	$T_0$	N	DD	$T_0$
Egg	20 EM	63	11.3	20 EM	63	11.3	20 EM	69	10.5
L1	177	40 <sup>a</sup>	8.6	153	47 <sup>b</sup>	9.1	190	37 <sup>a</sup>	7.6
L2	167	32 <sup>a</sup>	9.2	126	40 <sup>b</sup>	10.3	185	30 <sup>a</sup>	10.3
L3	160	36 <sup>a</sup>	9.4	93	49 <sup>b</sup>	7.6	176	33 <sup>a</sup>	9.3
L4	154	54 <sup>a</sup>	9.2	74	97 <sup>b</sup>	11.6	167	50 <sup>a</sup>	9.6
L1–L4*	154	162		74	233		167	150	
L1–A*	127	364		49	452		140	358	
Egg–A*	– <sup>1</sup>	427		– <sup>1</sup>	515		– <sup>1</sup>	426	

a,b = DD values followed by the same letter in a row are not significantly different ( $P > 0.05$ , Student–Newman–Keuls and Duncan Waller tests).

<sup>1</sup> = Number of eggs per egg mass (EM) not determined, \* = Determined by addition of stage-specific DD listed in this table;  $T_0$  values not significantly different.

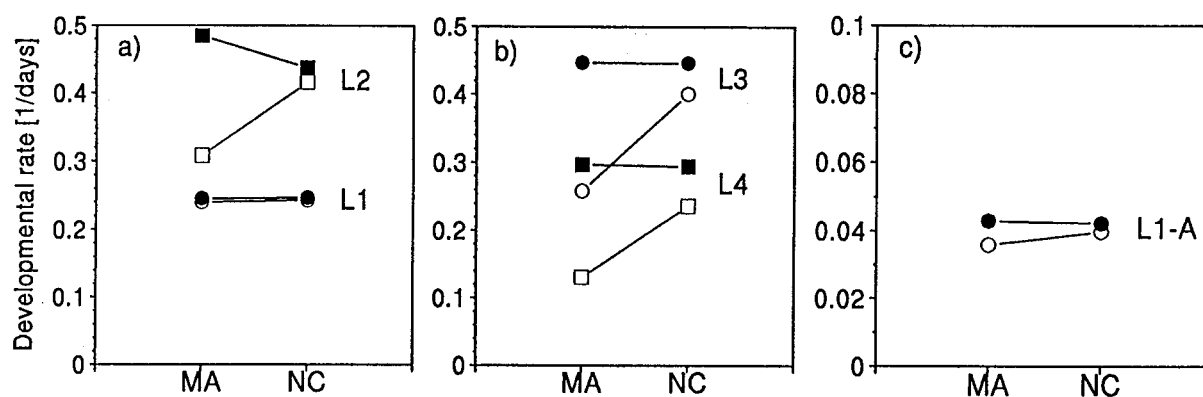


Figure 4. Fluctuating temperature regime (average temperature = 25 °C): Interaction plots of stage-specific developmental rates of first (L1), second (L2), third (L3) and fourth (L4) instars, and total preimaginal life (L1 through A) for all Colorado potato beetle colony by host plant combinations (P = potato; HN = horse-nettle; MA = Massachusetts; NC = North Carolina).

velopment from first instar to adult ( $P = 0.0003$ ), but not for the first instar (Figure 4). On horse-nettle, NC larvae had higher development rates than MA larvae in all instars except the first, whereas on potato, larvae from both colonies had similar development rates in all instars, except perhaps the second, in which MA larvae tended to have a higher development rate than NC larvae. The development rate of first instars was similar for all host and colony combinations.

## Discussion

The day-degree requirements for development to adult on potato were almost identical for beetles from the NC and MA colonies, despite the latitudinal separation of the populations from which these colonies

originated (MA 42° N lat.; NC 35° N lat.). Tauber et al. (1988) reported similar day-degree requirements for a Colorado potato beetle population originating from a warmer location and one originating from a cooler location in New York. Additionally, Goryshin et al. (1987) reported generally similar development rates on potato among Colorado potato beetle larvae originating from geographically distinct populations in eastern Europe. Together, these findings indicate that differences in the thermal requirements among geographically separate populations are minimal. Consequently, development rate/temperature relationships and thermal unit requirements for Colorado potato beetle development on a given host plant should be suitable for use in the development of temperature-driven population phenology models or pest manage-

ment decision aid models for the same host plant in other geographic regions. However, such models would not necessarily be valid for other host plants.

Our findings clearly indicate that the ability of Colorado potato beetle to use horse-nettle as a larval host plant was strongly influenced by temperature, and that the effects of temperature differed greatly between beetles from colonies originating from geographically separate populations. Temperature influenced survival to adult and development rate of larvae on both potato and horse-nettle, but the effects of temperature were dramatically different between beetles from the NC and MA colonies only on horse-nettle. Larvae from the MA colony did not complete development to adult on horse-nettle at constant temperatures below 30 °C. At the 30 °C constant temperature regime and at the fluctuating temperature (mean temperature 25 °C) regime, survival of some MA larvae on horse-nettle did occur but was relatively low (10 and 15%, respectively). In contrast, some larvae from the NC colony on horse-nettle survived to the adult stage at all temperature regimes above 12 °C, but survival increased dramatically at constant temperatures above 22 °C and was comparable to that on potato in the 30 °C constant temperature and the fluctuating temperature regimes. The development rates of early instar larvae (first and second instar) from both colonies were generally comparable across a broad range of temperatures on horse-nettle and potato. However, development rates for later instars (third and fourth instar) at constant temperatures above 17 °C and at the fluctuating temperature regime were lower on horse-nettle than potato, and on horse-nettle were lower for larvae from the MA than the NC colony. Because, on potato, the development rates of MA larvae were similar to or slightly greater than those of NC larvae, the differences between colonies on horse-nettle likely reflect poor adaptation of the MA beetles to horse-nettle as a larval host, rather than genetically based differences between the NC and MA larvae in thermal requirements for development. This has been shown to be the case in other insect-plant systems (Ritland & Scriber, 1985).

Although on horse-nettle at 30 °C MA larvae had lower development rates than NC larvae in the second, third and fourth instars, the preimaginal development rates for beetles surviving to adult (first instar to adult) were virtually the same for both the MA and NC colonies. This apparent discrepancy is due to mortality of slower developing individuals that were poorly adapted to horse-nettle. Given that variation among

Colorado potato beetle populations in the ability to use horse-nettle as a larval host is genetically based (Hare & Kennedy, 1986), our findings suggest the hypothesis that adaptation to horse-nettle may be facilitated by a genotype by environment interaction involving temperature. Under this hypothesis, high temperatures, which allow for significant survival to the adult stage, could permit the occurrence of selection for a more complete adaptation to horse-nettle that is characterized by higher survival and higher development rates over a broader range of temperatures. High temperatures, however, need not be a prerequisite for adaptation to horse-nettle to occur, but rather may merely facilitate selection for improved performance by allowing survival of individuals on which such selection could occur.

This hypothesis predicts that, with other things being equal, adaptation to horse-nettle should occur more rapidly in Colorado potato beetle populations that regularly experience periods during which temperatures are high and suitable alternatives to horse-nettle are not available, than in populations that experience comparable periods during which suitable alternatives to horse-nettle are unavailable, but temperatures are lower and allow few, if any, beetles to survive on horse-nettle. The former conditions are typical in the Coastal Plain of North Carolina where horse-nettle is common in meadows and along field margins and road sides throughout the summer when potato and other suitable host plants are unavailable and daily temperatures are consistently high. The occurrence of horse-nettle adapted Colorado potato beetle populations in northern locations such as southwestern Michigan, where potatoes have not been produced commercially for approximately 40 years (Mena-Covarrubias et al., 1996), likely reflects a response to selection imposed by the prolonged absence of suitable alternative hosts and the predictable availability of horse-nettle. Similarly, in Colorado, differences between two Colorado potato beetle populations in performance on the weed *Solanum sarrachoides* were associated with differences in abundance and predictability of *S. sarrachoides* relative to other potential host species (Horton et al., 1988). The degree to which genotype by environment interactions involving temperature have influenced Colorado potato beetle adaptation to horse-nettle in the NC and Michigan populations, as well as other field populations cannot be determined after the fact. Additional experiments will be required to fully test this hypothesis.



The mechanisms by which temperature differentially affects the ability of Colorado potato beetle populations to utilize horse-nettle as a host plant are not known, but could involve temperature mediated changes in the insects as well as in the plant (Benedict & Hatfield, 1988). Regardless of the mechanisms involved, the occurrence of genotype by environment interactions affecting host plant suitability has important implications for understanding spatial and temporal patterns of host plant utilization, host range expansion and the selection of pest biotypes adapted to plant resistance traits used in crop protection.

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