

ESTIMATE OF *Alabama argillacea* (HÜBNER) (LEPIDOPTERA: NOCTUIDAE) DEVELOPMENT WITH NONLINEAR MODELS

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ABSTRACT

The objective of this work was to evaluate which nonlinear model [Davidson (1942, 1944), Stinner *et al.* (1974), Sharpe & DeMichele (1977), and Lactin *et al.* (1995)] best describes the relationship between developmental rates of the different instars and stages of *Alabama argillacea* (Hübner) (Lepidoptera: Noctuidae), and temperature. *A. argillacea* larvae were fed with cotton leaves (*Gossypium hirsutum* L., race *latifolium* Hutch., cultivar CNPA 7H) at constant temperatures of 20, 23, 25, 28, 30, 33, and 35°C; relative humidity of $60 \pm 10\%$; and photoperiod of 14:10 L:D. Low R^2 values obtained with Davidson (0.0001 to 0.1179) and Stinner *et al.* (0.0099 to 0.8296) models indicated a poor fit of their data for *A. argillacea*. However, high R^2 values of Sharpe & DeMichele (0.9677 to 0.9997) and Lactin *et al.* (0.9684 to 0.9997) models indicated a better fit for estimating *A. argillacea* development.

Key words: cotton leafworm, developmental rate, *Gossypium hirsutum*, temperature.

RESUMO

Estimativa do desenvolvimento de *Alabama argillacea* (Hübner) (Lepidoptera: Noctuidae) por meio de modelos não lineares

O objetivo deste estudo foi avaliar qual modelo não linear [Davidson (1942, 1944), Stinner *et al.* (1974), Sharpe & DeMichele (1977) e Lactin *et al.* (1995)] descreve melhor a relação entre as taxas de desenvolvimento dos diferentes ínstar e fases de *Alabama argillacea* (Hübner) e a temperatura. As lagartas de *A. argillacea* foram alimentadas com folhas de algodoeiro (*Gossypium hirsutum* L., raça *latifolium* Hutch., cultivar CNPA 7H) e submetidas às temperaturas constantes de 20, 23, 25, 28, 30, 33 e 35°C, umidade relativa de $60 \pm 10\%$ e fotoperíodo de 14 horas. Os baixos valores de R^2 obtidos para os modelos de Davidson (0,0001 a 0,1179) e de Stinner *et al.* (0,0099 a 0,8296) indicaram que eles não são adequados para estimar o desenvolvimento de *A. argillacea* em função da temperatura. Entretanto, os altos valores de R^2 dos modelos de Sharpe & DeMichele (0,9677 a 0,9997) e de Lactin *et al.* (0,9684 a 0,9997) indicaram que os mesmos estimam, adequadamente, o tempo de desenvolvimento de *A. argillacea* em função da temperatura.

Palavras-chave: curuquerê-do-algodoeiro, taxa de desenvolvimento, algodoeiro, temperatura.

INTRODUCTION

Alabama argillacea (Hübner) (Lepidoptera: Noctuidae) is a native species of Central and South America found in most areas where cotton is cultivated, from South Canada to northern Argentina (Carvalho, 1981). This species occurs during the whole cultivation period of cotton plants, with increasing populations as the cycle progresses. This insect defoliates cotton plants from the lower to the upper parts, with most damage occurring during the last three instars (Belletini *et al.*, 1999). *A. argillacea* is the main cotton defoliator pest, greatly impacting cotton plant productivity in Argentina, Brazil, Colombia, Mexico, Nicaragua, Paraguay, Peru, and the USA (Almestar *et al.*, 1977; Falcon & Daryl, 1977; Cies, 1978; Alvarez & Sanchez, 1982; Nyffeler *et al.*, 1987; Michel, 1994; Ramalho, 1994; Lobos, 1999). *A. argillacea* is a lesser pest in South-Central Brazil but, except for the State of Bahia, in the Northeast this pest can cause damage during the whole cotton crop cycle (Gravena & Cunha, 1991).

The introduction of another cotton pest in Brazil, *Anthonomus grandis* Boheman (Coleoptera: Curculionidae), complicated pest control in this crop, resulting in a significant reduction in the area cultivated (Ramalho *et al.*, 1989). New areas for agriculture in Brazil such as the savannah regions in the States of Mato Grosso do Sul and Goiás have added the importance of *A. argillacea* as a cotton crop pest. Besides, the appearance of populations resistant to insecticides has been increasing problems with pest control in this crop.

The relationship between insect developmental rate and temperature represents an important ecological variable for modelling population dynamics of these organisms. Linear models were the first developed for insects (Howe, 1967) but the lack of linearity of insect developmental rate at low and high temperatures suggests that such models are inadequate to describe this parameter for these organisms. Since early 1980 this problem has led to increasing interest in developing nonlinear phenological models in integrated pest management programs (Wagner *et al.*, 1984).

Nonlinear models (Logan *et al.*, 1976) have been elaborated for several insect species in certain circumstances. Davidson (1942, 1944) described the insect developmental rate as a function of temperature

using logistic equations. Stinner *et al.* (1974) described the temperature effect on developmental rate as a modified sigmoid equation that results in a symmetrical curve at higher temperatures. Sharpe & DeMichele (1977) formulated a complex biophysical model, later modified by Schoolfield *et al.* (1981), which describes a nonlinear response of developmental rate of insects exposed to low and high temperatures as well as a linear response at intermediate temperatures (Wagner *et al.*, 1984). Lactin *et al.* (1995) modified the nonlinear model of Logan *et al.* (1976) by eliminating the parameter ψ and introducing parameter intercepts λ , which allowed estimation of the developmental threshold.

Because linear models are not very precise sources of information on developmental rate inhibition at extreme temperatures, the purpose of this research was to determine which nonlinear model (Davidson, 1942, 1944; Stinner *et al.*, 1974; Sharpe & DeMichele, 1977; Lactin *et al.*, 1995) better describes the temperature effect on the developmental rate of *A. argillacea*.

MATERIAL AND METHODS

This research was developed at the Biological Control Unit (UCB)/Embrapa Algodão, in Campina Grande, State of Paraíba, Brazil. Specimens of *A. argillacea* were collected in Touros, State of Rio Grande do Norte, and maintained in BOD at constant temperatures of 20, 23, 25, 28, 30, 33, and 35°C, relative humidity of 60 ± 10%, and photoperiod of 14:10 L:D. Larvae of this species were fed with cotton plant leaves (*Gossypium hirsutum* L., race *latifolium* Hutch., cultivar CNPA 7H) while adults received a solution of honey (20%) and distilled water (80%).

Newly emerged adults were used to form 15 pairs of *A. argillacea*, with five of them per PVC cage (Medeiros, 1997). First egg clutches of *A. argillacea* were placed in Petri dishes (9.0 x 1.5 cm) with a moist cotton ball, and observed daily to determine their incubation period and viability at the same temperatures and humidity conditions used for *A. argillacea* pairs.

The fifty-first instar of *A. argillacea* larvae were individualized in plastic cups (250 ml) for each treatment. A cylindrical plastic tube (2.5 cm) with distilled water was inserted in a circular hole in the cover of each plastic cup. One fresh cotton leaf was

removed from apical parts of plants and used daily as food for *A. argillacea* larvae. The dorsal surface of these larvae was marked with dye (Day-Glo Colour Corp) to facilitate observation of ecdyses. Everyday, results were recorded and cotton leaves substituted.

Mean developmental rate of egg, instars, prepupae, and pupae of *A. argillacea* at different temperatures was estimated with the formula:

$$r(T) = 1.0 / e^{\left\{ \left[\sum_{i=1}^n \ln(di) \right] / n \right\}}$$

where $r(T)$ is the mean developmental rate at temperature T (°C); di , individual observations of development period in days; and n , number of observations.

This method is recommended by Logan *et al.* (1976) to account for linearity in the transformation of development period to developmental rate.

Developmental rate is the reciprocal of development period in days and represented by values from 0 to 1. These rates are used in development models where data are added daily. Organism development is completed when the sum of their daily developmental rate reaches value 1 (Curry & Feldman, 1987). Therefore, the integral of the developmental rate function along time (as in the models of Davidson, 1942, 1944; Stinner *et al.*, 1974; Sharpe & DeMichele, 1977; Lactin *et al.*, 1995) can be used to simulate the development of an organism submitted to different temperatures. For this reason, descriptive nonlinear procedures have been used to analyze relationships between developmental rate of *A. argillacea* and temperature as:

1) logistic equation of Davidson (1942, 1944):

$$r(T) = \frac{k}{(1 + e^{a-bT_i})},$$

where $r(T)$ is the mean developmental rate at temperature T (°C); a , value which defines the place of the regression line in relation to the x axis; b , slope of the curve line; k , constant defining the upper limit of the sigmoid line; T_i , temperature in the environmental chamber.

The parameters a , b , and k were estimated with the regression nonlinear model of Marquardt using PROC NLIN (Sas Institute Inc., 2000). This method is used to determine the minimum square of the parameters estimated with this model.

2) sigmoid equation of Stinner *et al.* (1974):

$$r(T) = \frac{c}{(1 + e^{k_1 + k_2 T'})},$$

where $r(T)$ is the mean developmental rate at temperature T (°C); c , $(1/T_{max}) \times (e^{k_1 + k_2 T_{max}}$) (asymptote); k_1 and k_2 , empirical constants; and $T' = T$, for $T < T_{max}$ and $T' = 2 \times T_{max} - T$, for $T > T_{max}$.

The parameters c , k_1 , and k_2 were estimated with Marquardt's method using PROC NLIN (Sas Institute Inc., 2000).

3) biophysical model of Sharpe & DeMichele (1977), modified by Schoolfield *et al.* (1981):

$$r(T) = \frac{RHO_{25} \left(\frac{T}{298.15} \right) \exp \left[\left(\frac{H_A}{R} \right) \left(\frac{1}{298.15} - \frac{1}{T} \right) \right]}{1 + \exp \left[\left(\frac{H_L}{R} \right) \left(\frac{1}{T_L} - \frac{1}{T} \right) \right] + \exp \left[\left(\frac{H_H}{R} \right) \left(\frac{1}{T} - \frac{1}{T_H} \right) \right]}$$

where $r(T)$ is the mean developmental rate at temperature T (°K); R , universal gas constant (1.987 cal degree⁻¹mole⁻¹); RHO_{25} , developmental rate at 25°C (298.15°K), assuming no enzyme inactivation; H_A , enthalpy of activation of the reaction catalyzed by a rate-controlling enzyme; T_L , Kelvin temperature at which the rate-controlling enzyme is half active and half low-temperature inactive; H_L , change in the enthalpy associated with low temperature inactivation of the enzyme; T_H , Kelvin temperature at which the rate-controlling enzyme is half active and half high-temperature inactive; and H_H , change in the enthalpy associated with high-temperature inactivation of the enzyme.

Parameters RHO_{25} , H_A , T_H , and H_H were estimated with Marquardt's method using PROC NLIN (Sas Institute Inc., 2000), with the procedure adopted by Wagner *et al.* (1984).

The numerator of the Sharpe & DeMichele (1977) equation explains the dependence of developmental rate with temperature in the absence of inactivation at low or high temperatures, while the first and the second exponential equations in the denominator explain respectively the inhibition at low and high temperatures (Wagner *et al.*, 1984). These authors developed a method to determine if a model with six, four, or two parameters adjusts to the data. This method tests the nonlinearity of data for extreme temperatures (low and high), that would indicate inhibition at those temperatures. The model is constituted by six parameters and is better adjusted to data if both extreme temperatures have a significant effect on inhibition. The parameters T_H and H_H assume constant values of 1,000 and 100,000,000, respectively, when high temperatures have no significant effect on inhibition. If low temperatures have no significant effect on inhibition, the parameters T_L and H_L receive constant values of 100 and -100,000,000, respectively. Therefore, the model with four parameters will be better adjusted to data in both cases. When both low and high temperatures have no effect on inhibition, the model with two parameters is better adjusted to data; and the four parameters T_H , H_H , T_L , and H_L will have constant values of 1,000; 100,000,000; 100; and -100,000,000, respectively.

4) The model of Lactin *et al.* (1995) resulted from modifications in the nonlinear model of Logan *et al.* (1976):

$$r(T) = e^{rT} - e^{\left[rT_L - \left(\frac{T_L - T}{\Delta_r} \right) \right]} + I,$$

where $r(T)$ is the mean developmental rate at temperature T (°C); T_L , lethal temperature (°C); ρ , rate of increase at optimal temperature; Δ_r , difference between the lethal and optimal temperature of development; and λ , the parameter that makes the curve intercept the x -axis, allowing the estimation of a developmental threshold.

The parameters T_L , ρ , Δ_r , and λ were estimated with the method of Marquardt using PROC NLIN (Sas Institute Inc., 2000).

Determination coefficient (R^2) of nonlinear models cannot be calculated with linear models [$R^2 = 1 - (\text{SQR}/\text{SST})$], because most of the nonlinear models show non-identifiable intercepts. In this case, the Sas uses the sum of the noncorrelated squares instead of the sum of total squares (Freund & Littell, 1986). The R^2 of these models were calculated as $R^2 = 1 - (S_y^2/S_{\text{id}}^2)$, where S_y^2 is the variance of the residues of the model and S_{id}^2 is the variance of observed means of developmental rate.

TABLE 1
Developmental rate of *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leaves of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of 60 ± 10%, and photoperiod of 14:10 L:D.

Temp. (°C)	Stage			
	Egg	Larvae	Prepupae	Pupae
20	0.2000	0.0527	0.6648	0.0734
23	0.2500	0.0602	1.0000	0.0920
25	0.3333	0.0676	1.0000	0.1068
28	0.5000	0.0847	1.0000	0.1539
30	0.5000	0.0911	1.0000	0.1775
33	0.5000	0.1069	1.0000	0.2001

RESULTS

The developmental rate of eggs, larvae, prepupae, and pupae of *A. argillacea* was proportional to temperature increase, except for eggs at 28, 30, and 33°C and prepupae at 23, 25, 28, 30, and 33°C (Table 1).

The R^2 values for the logistic model of Davidson (1942, 1944) from 0.0001 to 0.1179 (Table 2) and the sigmoid model of Stinner *et al.* (1974) from 0.0099 to 0.8296 (Table 3) were low, which suggests that neither are appropriate for describing data obtained with *A. argillacea*. On the other hand, high values of R^2 for the biophysical model of Sharpe & DeMichele (1977) from 0.9677 to 0.9997 (Table 4), and Lactin *et al.* (1995) from 0.9685 to 0.9997 (Table 5) showed better adjustment to *A. argillacea* data.

Inhibition of development of *A. argillacea* due to temperature occurs at 35°C, while this was not significant at 20°C. The version of the Sharpe & DeMichele (1977) model had values of 100 and -100,000,000 for T_L and H_L , respectively, because inhibition of development of *A. argillacea* was significant at higher temperatures.

Larvae of *A. argillacea* showed higher tolerance to high temperatures which is represented by a high value of H_H with the model of Sharpe & DeMichele (1977) (Table 4) and a low value of Δ_T with the model of Lactin *et al.* (1995) (Table 5).

The value of the parameter T_H of the Sharpe & DeMichele (1977) model is the temperature (°K) at which the enzyme that controls developmental rate of insects is partially inhibited. Value of T_H for *A. argillacea* was 306.3°K (Table 4), therefore this species presents thermal stress at 33.3°C. This indicates that the estimate of maximum thermal action by the model of Sharpe & DeMichele (1977) was realistic.

The parameter T_L of the model of Lactin *et al.* (1995) represents the temperature (°C), at which the insect does not survive for a long period. The estimated T_L values for *A. argillacea* were similar to those observed (Table 5), because transformation of these values to current temperatures ($T_L + 20$) shows that the lethal one for *A. argillacea* is 56.83°C. The λ values calculated with the model of Lactin *et al.* (1995) were < 0 (Table 5), indicating that this model can be used to calculate minimum temperature for each instar and developmental stage of *A. argillacea*.

TABLE 2

Estimated parameters with the Davidson model for *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leave of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of $60 \pm 10\%$, and photoperiod of 14:10 L:D.

Stage	Parameter			R^2
	k	a	b	
Egg	0.3667	10.4375	0.5200	0.1179
1 st instar	0.3089	11.8948	0.6559	0.0299
2 nd instar	0.5614	7.9058	0.4197	0.0649
3 rd instar	0.5466	7.8061	0.4118	0.0677
4 th instar	0.3446	17.1872	0.9363	0.0194
5 th instar	0.2289	153.7000	7.7464	0.0271
Larvae	0.0698	9.7340	0.5396	0.0362
Prepupae	0.8193	-8.4813	348.4000	0.0001
Pupae	0.1301	8.9179	0.4520	0.0993
Immature	0.0381	9.5642	0.5101	0.0631

k = constant defining the upper limit of the sigmoid line.

a = value defining the place of the regression line in relation to the x axis.

b = slope of the curve line.

TABLE 3

Estimated parameters with the Stinner *et al.* model for *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leaves of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of 60 ± 10%, and photoperiod of 14:10 L:D.

Stage	Parameter			R ²
	c	k ₁	k ₂	
Egg	0.3667	10.4374	-0.5200	0.1179
1 st instar	0.3089	11.8948	-0.6559	0.0299
2 nd instar	0.5961	-1,007.0000	29.1355	0.5815
3 rd instar	0.5772	-884.0000	25.6205	0.5606
4 th instar	0.3910	-13,377.9000	382.6000	0.8218
5 th instar	0.3859	-11,992.3000	343.0000	0.8296
Larvae	0.0774	-883.5000	25.5952	0.7135
Prepupae	0.8333	80.4919	-4.1251	0.0099
Pupae	0.1301	8.9179	-0.4520	0.0992
Immature	0.0381	9.5640	-0.5101	0.0631

c = asymptote.

k₁ and k₂ = empirical constants.

TABLE 4

Estimated parameters with the Sharpe & DeMichele model for *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leaves of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of 60 ± 10%, and photoperiod of 14:10 L:D.

Stage	Parameter				R ²
	RHO ₂₅	H _A	T _H	H _H	
Egg	0.3323	16,494.5000	306.3000	1,159,017.0000	0.9770
1 st instar	0.5072	12,786.6000	307.6000	5,074,682.0000	0.9961
2 nd instar	0.5072	12,786.6000	307.6000	5,074,682.0000	0.9961
3 rd instar	0.4852	13,492.4000	307.5000	4,394,011.0000	0.9965
4 th instar	0.3661	7,842.8000	306.4000	1,958,619.0000	0.9993
5 th instar	0.2320	10,414.8000	306.4000	2,042,168.0000	0.9951
Larvae	0.0696	10,109.4000	306.4000	2,089,653.0000	0.9986
Prepupae	0.9409	3,326.5000	306.4000	1,818,217.0000	0.9677
Pupae	0.1142	15,824.9000	306.3000	1,935,500.0000	0.9971
Immature	0.0365	12,345.8000	306.3000	1,966,288.0000	0.9997

RHO₂₅ = developmental rate at 25°C (298.15°K), assuming no enzyme inactivation.

H_A = enthalpy of activation of the reaction catalyzed by a rate-controlling enzyme.

T_H = temperature (°K) at which the rate-controlling enzyme is half active and half high temperature inactive.

H_H = change in enthalpy associated with inactivation of the enzyme at high temperature.

TABLE 5

Estimated parameters with the Lactin *et al.* model for *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leaves of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of 60 ± 10%, and photoperiod of 14:10 L:D.

Stage	Parameter				R ²
	r	T _L	D _T	l	
Egg	0.0211	36.3960	1.3179	-1.3466	0.9823
1 st instar	0.0136	35.9980	0.8864	-1.0804	0.9897
2 nd instar	0.0234	35.0888	0.1076	-1.2707	0.9898
3 rd instar	0.0235	35.0914	0.1081	-1.2954	0.9863
4 th instar	0.0129	35.8229	0.7891	-1.0113	0.9997
5 th instar	0.0110	35.6559	0.4919	-1.0804	0.9926
Larvae	0.0038	35.8086	0.3502	-1.0299	0.9964
Prepupae	0.0132	35.3445	0.9301	-0.5212	0.9684
Pupae	0.0087	36.1203	0.6319	-1.1232	0.9905
Immature	0.0026	36.8295	0.6476	-1.0281	0.9955

ρ = rate of increase at optimal temperature.

T_L = lethal temperature (°C).

Δ_T = difference between development at lethal and optimal temperatures.

λ = parameter that makes the curve intercept the x-axis, allowing development threshold estimation.

Sharpe & DeMichele (1977) and Lactin *et al.* (1995) models appropriately described relationships between developmental rate and temperature for *A. argillacea* (Fig. 1).

DISCUSSION

The logistic equation of Davidson (1942, 1944) and the sigmoid model of Stinner *et al.* (1974) do not appropriately describe relationships between the developmental rate of different stages of *A. argillacea* and temperature.

Although these models have been used to describe the relationship between the developmental rate and temperature of insect species, they present the following problems: (1) the model of Stinner *et al.* (1974) assumes symmetrical shape at both sides of optimal temperature and for this reason does not appropriately describe insect development at high temperatures; and (2) the model of Davidson (1942, 1944) offers low descriptive precision at both ends of the relationship curves between developmental rate and temperature (Wagner *et al.*, 1984). Harari *et al.* (1998) pointed out that the Davidson (1942, 1944) model was not adequate in the case of development of *Maladera matrida* Argaman (Coleoptera:

Scarabaeidae) because it estimated longer developmental rate at higher rather than at optimal temperatures.

The biophysical model of Sharpe & DeMichele (1977) describes a nonlinear response between developmental rate at low and high temperatures, as well as a linear response at intermediate temperatures. For this reason, Wagner *et al.* (1984) and Fan *et al.* (1992) consider that this nonlinear model better describes the effect of constant temperatures on insect development. The model was applied and evaluated by Gould & Elkinton (1990), Orr & Obrycki (1990), Fan *et al.* (1992), Morales-Ramos & Cate (1993), Judd & McBrien (1994), and Harari *et al.* (1998) and was considered appropriate for determining developmental rate of organisms studied.

Lactin *et al.* (1995), modified the nonlinear model of Logan *et al.* (1976) by eliminating the parameter Ψ and introducing the parameter λ (intercept), which allowed estimation of development threshold for insects. The resulting model was applied and evaluated by Briere & Pracros (1998) and is appropriate for describing the relationship between developmental rate of different stages of *Lobesia botrana* Dennis & Schiffermüller (Lepidoptera: Tortricidae) and temperature.

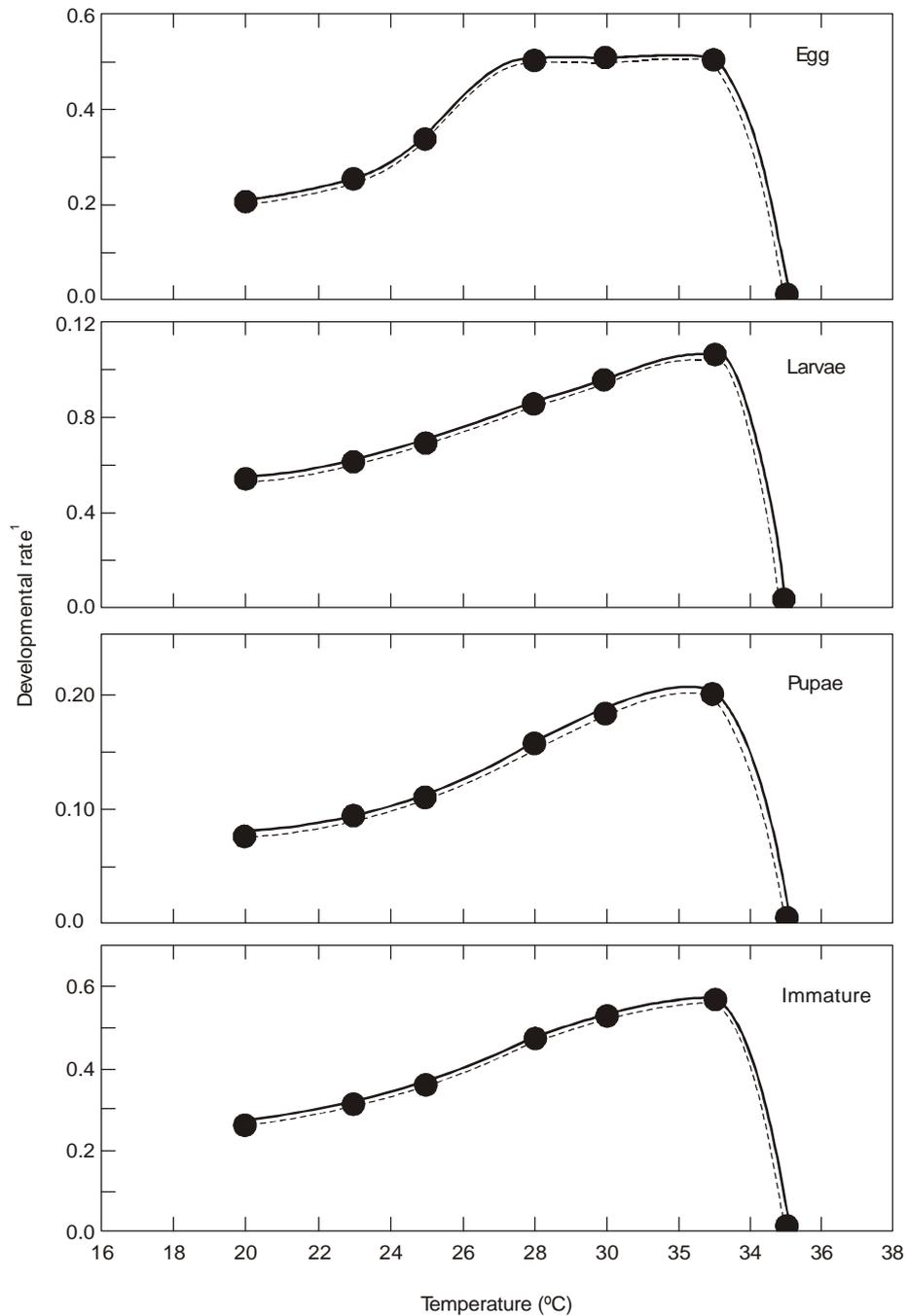


Fig. 1 — Relationship between developmental rate and temperature for different stages of *Alabama argillacea* (Lepidoptera: Noctuidae) fed with leaves of *Gossypium hirsutum* L. race *latifolium* Hutch., cultivar CNPA 7H, at temperatures from 20 to 33°C, relative humidity of $60 \pm 10\%$, and photoperiod of 14:10 L:D. Lactin *et al.* model (—). Sharpe & DeMichele model (---). Observed value (●).

$r(T) = 1.0 / e^{\left\{ \left[\frac{\sum \ln(di)}{n} \right] \right\}}$, where $r(T)$ is the mean developmental rate at temperature T (°C), di , individual observations of development period in days and n , number of observations.

Models of Sharpe & DeMichele (1977) and Lactin *et al.* (1995) were more precise for describing the relationship between developmental rate of different stages of *A. argillacea* and temperature (Fig. 1) because both described an asymmetrical shape around high temperatures (Fig. 1). Briere & Pracros (1998) stated that the relationship between developmental rate and temperatures in insects is nonlinear and presents an asymmetrical shape composed of three sections: the first is represented at low temperatures where the increase in developmental rate is nonlinear from development zero; the second section, where the developmental rate becomes proportional to temperature increase; and the third, which starts with the optimal and finishes with lethal temperature.

Our results suggest that Sharpe & DeMichele (1977) and Lactin *et al.* (1995) models are more precise for describing the relationships between developmental rate of different instars and stages of *A. argillacea* and temperature. These results can therefore be used to forecast the occurrence of different stages and instars of *A. argillacea* in cotton crops, and enable greater precision in choosing the best periods for controlling this pest.

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