动 物 学 研 究 1998, 19 (5): 389~396 CN 53-1040/Q ISSN 0254-5853
Zoological Research

TEMPERATURE-DEPENDENT DEVELOPMENT OF ASIAN CORN BORER *Ostrinia furnacalis*

LI Zheng-yue LU Mei-rong

(*Department of Entomology, Yunnan Agricultural University, Kunming* 650201)

Abstract Temperature-dependent development in the Asian corn borer, *Ostrinia furnacalis* (Guenee) was determined at nine constant temperatures between 10℃ and 34℃. Except for 10℃ development of all life stages occurred at the temperatures tested, however, mortality was significantly great at the extreme temperatures (12℃ and 34℃). Egg, larvae and pupae duration accounted for 17%, 57% and 25% of total one of immature stage, respectively. Lower developmental thresholds estimated to be 10.38, 10.06 and 11.07℃ for eggs, larvae and pupae, respectively. Upper limited thresholds were 28.00, 31.00 and 31.00℃ for eggs, larvae and pupae, respectively. The heat-unit requirements for egg stage were 79.15 degree-days, for larval stage were 339.73 degree-days, and for pupal stage were 128.82 degree-days, respectively. Overall, heat-unit requirements for development from egg to adult were 539.91 degree-days between lower developmental threshold 10.35℃ and upper limited threshold 32℃.

Key words Asian corn borer, Temperature development, Thresholds, Degree-days

The Asian corn borer, *Ostrinia furnacalis* (Guenee) is a major pest of corn, *Zea mays* L. in Yunnan Province. It seriously infests in over 280 000 hm^2, which account for 36% of the total cultivated area. The corn yield loss caused by the borer is estimated about 25 000 tons annually (Lu, 1992).

There have been several measures to control the corn borer, among which applying insecticides is still main one. No factor is more important in efficacy and environmental safety than proper timing of insecticide applications (Pedigo, 1989). Many researchers have pointed out that insecticide against them should be applied before the young larvae bore into stalk. And this period can be estimated by observing either the occurrence and magnitude of moth flight or appearance of egg mass (Apple, 1952; Showers *et al.*, 1983) while the thermal requirement for development of this species has been identified as much more efficient method to predict its phenology and has been successfully used in many areas (Apple, 1952; Jarvis *et al.*, 1965; Showers *et al.*, 1983; Bovin *et al.*, 1986). Unfortunately, information in this respect is unavailable for the corn borer in Yunnan.

Our study was conducted to determine the stage specific temperature-dependent development of the Asian corn borer over a wide range of temperatures.

本文1997-09-18收到，1998-02-10修回

1 Materials and Methods

Original adult moths were obtained from field collected the parasitic-free overwintered larvae in cornstalks and in corn cobs in Yongde, Yunnan from February through April 1995. The adult moths used in this study were from the second laboratory-reared generation.

The adult moths were reared at (25±0.5)℃ of a wooden cage in growth chamber to obtain egg clusters. Nine different constant temperatures, all in conjunction with a photoperiod 16:8 (L:D) h and RH (70±4)%, were used: 10, 12, 14, 16, 18, 22, 26, 30 and 34℃. Newly hatched larvae were transferred from the Petri dish with a wet camel's hair brush onto the artificial diet developed by Zhou *et al*. (1980). 50 less than 24 hour old eggs were introduced into a 10 cm×15 cm disposable Petri dish. Four replicates were run for each treatment with total 200 eggs throughout the study. Each Petri dish was removed singly every 24 hour for examination. Daily observations including monitor survival numbers and time of ecolsion in each event were continued until the moth reached the adult stage. The number of days required for each stage of development from egg to adult emergence was recorded. The theoretical threshold temperatures and degree-days were determined by these data.

An analysis of variance (ANOVA) was used to examine the effects of temperatures on developmental times and survival numbers.

The equation as suggested by Stinner *et al*. (1974) was used to estimate sigmoid functions and determine the upper threshold temperatures in each life stage of *O. furnacalis*:

$$R_t = \frac{C}{1 + e^{k_1 + k_2 T'}}$$

where:

R_t = rate of development (1/time) at temperature T

C = (maximum developmental rate) $\times e^{k_1 + k_2 \text{top}t}$, i.e. the asymptote

k_1, k_2 = empirical constants

$T' = T$, for $T \leqslant \text{top}t$

$T' = 2 \times \text{top}t - T$, for $T > \text{top}t$

top$t$ = temperature at which the maximum developmental rate occurs

SYSTAT Pro (SYSTAT Inc. 1990) was used to estimate the parameters. In this formula, top$t$ was employed as upper threshold (Stinner *et al*., 1974; Calvin *et al*., 1991).

The linear regression technique was employed by using the growth rate data as the dependent variable (y-axis) and temperatures as the independent variable (x-axis). The minimum developmental threshold temperature was determined as the x-intercept of the linear equation relating temperature to growth rate (Pedigo, 1989) from the statistical program in Quatro-Pro (Borland, Scott's Valley, CA).

The equation suggested by Lin *et al*. (1954) was used to calculate degree-day requirements as:

$$K = d_i(t_i - a)$$

where K is the thermal constants (degree-days); t_i is the temperatures of incubation, d_i is the mean number of days in incubation at the ith temperature, and a is the minimum developmental threshold temperature.

The duration of development z was approximated by

$$z = a/(T - x)$$

where a is the average degree-day requirements; T is temperature, and x is the lower developmental threshold (Miller *et al.*, 1992). By this procedure, the growth model for this moth was constructed and its growth rate was calculated.

2 Results and Discussion

The results from present experiments showed that as temperature increased from 12℃ to 26℃ developmental time of egg stage decreased and there was an obvious linear relationship between developmental rate and temperature in this range (Table 1). The minimum developmental threshold temperature by simple linear regression of developmental rate as a function of temperature taken from the linear part (12, 14, 16, 18, 22 and 26℃) of the developmental rate curve, and then extrapolating to zero. It was estimated by the linear regression that low developmental threshold temperature of egg stage was 10.34℃. The data suggested averaging degree-days for egg stage was 79.15 ± 5.18.

Table 1 Developmental time (day) of Asian corn borer at different temperatures

Life stage	Temperature/℃								
	10	12	14	16	18	22	26	30	34
Egg	no hatch	36.8^{a}① ±5.1	28.5^{ab}±1.2	16.3^{bc}±1.3	10.8^{c}±0.8	6.5^{c}±1.0	4.3^{c}±0.9	4.5^{c}±1.5	4.8^{c}±2.5
Larval instar									
1	–	21.5^{a}±0.7	18.3^{b}±0.9	10.8^{c}±0.9	7.3^{d}±0.5	4.8^{e}±0.5	3.5^{ef}±0.3	2.8^{f}±0.3	3.5^{ef}±0.7
2	–	15.5^{a}±3.2	13.3^{a}±1.1	7.8^{b}±0.5	5.5^{bc}±0.7	3.8^{c}±0.5	2.8^{c}±0.6	2.5^{c}±0.7	1.8^{c}±0.5
3	–	14.8^{a}±3.5	12.0^{a}±0.9	7.3^{b}±0.6	4.5^{bc}±0.6	4.0^{bc}±0.7	2.8^{c}±0.9	2.0^{c}±0.8	2.7^{c}±0.7
4	–	no maturity	15.8^{a}±0.5	9.5^{b}±0.9	6.3^{bc}±0.8	4.3^{cd}±0.8	3.0^{d}±0.4	2.5^{d}±0.7	2.8^{cd}±0.5
5	–	–	36.8^{a}±1.0	23.5^{b}±1.3	16.5^{c}±0.8	9.8^{d}±0.8	8.3^{de}±0.4	6.8^{e}±0.7	6.3^{e}±0.5
Total	–	–	96.2±0.9	58.9±0.8	40.1±0.7	26.7±0.7	20.4±0.5	16.6±0.6	17.1±0.6
Pupa	–	–	43.5^{a}±2.9	25.3^{b}±2.3	17.8^{c}±0.9	12.0^{d}±0.4	9.5^{de}±0.7	6.5^{e}±0.7	7.3^{e}±0.5
Egg to Adult	–	–	168.2^{a}±1.9	100.5^{b}±1.8	68.7^{c}±1.4	45.2^{d}±1.3	34.2^{de}±1.3	27.6^{e}±1.5	29.2^{e}±1.7

① Values in the table indicates $M \pm SE$ followed by different letters differ significantly ($P<0.05$).

The top*t* was determined visually from the curve of developmental rates in Fig. 1 and the upper limit temperature (top*t*) for this species at egg stage would be about 28℃.

No eggs hatched at 10℃ but very few eggs hatched at 12℃. The hatching rate of egg stage also was significantly different at different temperatures. $F = 39.46$; $DF = 7, 21$; $P < 0.0001$. Egg mortality was significantly greater at temperature extremes than at moderate temperatures.

In larval stage of moth, the developmental rate increased as temperature increased until 34℃ (Table 1). F test indicates this effect of temperature was significant. The linear part (14, 16, 18, 22, 26 and 30℃) of the developmental rate relating to temperatures was employed for each instar and the total combined instars of larva to establish linear regression equations. Each instar and the total combined instars of larva were similarly responded to this linear part. Series of simple linear equations for each instar and the combined total instars larva were developed according to the data in Table 1.

For each instar and the total combined instars of larva, the minimum threshold temperature values ranged from a low of (9.70 ± 0.02)℃ at the second instar to a high of (10.92 ± 0.008)℃ at the fourth instar. The other minimum threshold temperatures were: (10.88 ± 0.003)℃ for the first instar; (10.33 ± 0.03)℃ for the third instar; (10.03 ± 0.006)℃ for the fifth instar; and (10.06 ± 0.01)℃ for total combined instars. Degree-days for each instar was calculated according to their individual minimum threshold temperature with developmental time. The first instar and the fifth instar required relatively more degree-days which was 51.90 ± 4.32 and 136.37 ± 4.16, respectively. They were in accordance with their longer developmental times. Other instars had some less degree-days, that is, second instar was 46.81 ± 2.18; third instar was 42.31 ± 3.94; fourth instar was 49.53 ± 2.41; and the total combined instars, the degree-days was 336.7 ± 312.71. In the same way, sigmoid growth models in each instar and the total combined instars of larvae were used to estimate the upper threshold temperatures for each of them. The results showed that sigmoid developmental equations were consistent with these data, as indicated by R^2 values > 0.90 with the exception of 0.832 at third instar. Upper threshold temperature values for larval stage were 32, 35, 31, 30, 35 and 32℃ for first, second, third, fourth, fifth instar and the total combined instars, respectively.

Table 2 The survival numbers of Asian corn borer at different constant temperatures

Life stage	Temperature/℃								
	10	12	14	16	18	22	26	30	34
Egg	no hatch	3.8^{e}±1.03	18.0^{d}±2.97	25.3^{d}±0.75	31.3^{c}±1.65	37.0^{ab}±0.92	39.0^{a}±0.92	41.8^{a}±1.29	22.0^{d}±2.11
Larval instar									
1	–	3.8^{e}±0.86	18.0^{d}±3.82	25.3^{cd}±1.25	31.3^{bc}±2.78	37.0^{ab}±1.47	39.0^{a}±1.47	41.8^{a}±1.65	22.0^{d}±2.2
2	–	2.8^{e}±1.40	16.3^{d}±1.85	23.0^{cd}±0.91	28.3^{bc}±1.82	35.0^{ab}±1.81	37.0^{a}±1.25	38.5^{a}±1.20	16.0^{d}±1.00
3	–	2.5^{e}±1.18	15.5^{cd}±3.23	21.5^{bc}±2.85	26.3^{b}±0.86	33.0^{a}±2.20	34.0^{a}±2.20	37.5^{a}±1.04	14.8^{d}±3.2
4	–	no maturity	14.5^{d}±2.10	16.0^{cd}±1.47	21.3^{c}±2.02	30.0^{a}±2.04	32.0^{ab}±2.58	36.0^{a}±1.83	8.3^{e}±0.86
5	–		10.1^{de}±3.12	15.0^{cd}±1.83	19.5^{c}±2.33	27.8^{b}±1.65	31.0^{ab}±0.82	35.0^{a}±0.92	6.8^{e}±1.85
Pupa	–		4.0^{de}±0.92	8.0^{d}±2.20	14.0^{c}±1.83	21.0^{b}±1.29	26.0^{a}±1.29	29.0^{a}±1.69	3.3^{e}±0.75

The data from Table 2 suggested that the survival numbers increased as temperature increased continuously with each higher temperature in larval stage. From temperatures between 14℃ and 18℃ survival numbers were 10.1 at the 14℃, 15.0 at the 16℃, and 19.5 at the 18℃, respectively. But between temperature 22℃ and 30℃, the survival numbers were obviously increased. The survival numbers at 22℃ were 27.8, and 31.0 at 26℃. Up to 30℃, the survival numbers arrived to the maximum, 35.0. However, at 12℃, larvae could survive through the third instar, but could not survive through the fourth instar. At 34℃, only about 7 individuals out of 50 initial individuals survived. In larval stage, extreme temperatures at lower and higher were obviously decreased the survival rates. The statistical analysis revealed that the survival rates of total larval stage were also significantly differing by temperature treatments. $F = 88$; $DF = 7, 24$; $P < 0.0001$.

The developmental time decreased as the treatment temperatures increased at the pupal stage. The minimum time of development occurred at 30℃, averaging 6.5 days. The growth rate reached to maximum. The developmental time was significantly by temperature treatments. $F = 56.2$; $DF = 6, 21$; $P < 0.00001$. From the estimation, minimum threshold temperature of pupal stage was determined to be (11.07 ± 0.008)℃ using linear part (14, 16, 18, 22, 26 and 30℃), the degree-days was 128.02 ± 3.99. Upper threshold was near 31.0℃. The survival numbers of pupal stage was significantly different by temperature treatments. $F = 49.11$; $DF = 6, 21$; $P < 0.00001$.

From 14℃ to 30℃, the number of Asian corn borer from newly pupation to adult emergence was gradually increased. Up to 30℃ the emergence adults arrived to maximum survival rate. However, the numbers of adult emergence drastically decreased when temperature was over 30℃. Only were 3.3 emergence adults at 34℃, which was the one tenth of that at 30℃. Mortality was significantly greater at temperature extremes 14℃ and 34℃ for pupa.

It should be noted that approximately 17% of the total duration of the immature stage was spent in the egg stage, about 57% in the larval stage, and about 25% in the pupal stage. The elapsed time from deposition of eggs to adult emergence of Asian corn borer varied from about 28 days at 30℃ to about 168 days at 14℃. The minimum developmental threshold of combined immature stages was captured by the linear part of velocity line within 14, 16, 18, 22, 26 and 30℃. When they extrapolated to zero, the lower developmental threshold was determined at (10.35 ± 0.02)℃. In like manner, the degree-day required for combined immature stage was estimated as the individual immature stages. The degree-day was 539.51 ± 8.62. Upper limited threshold also determined near 32.0℃ (Fig.1).

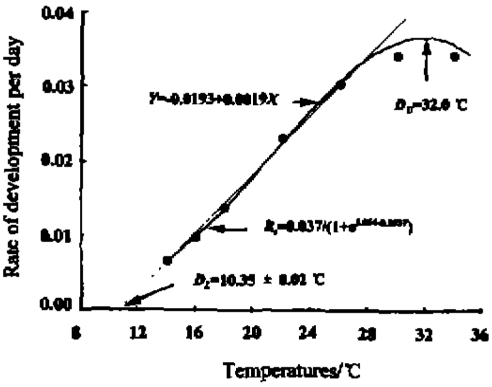

Fig.1 Relationship between daily developmental rate and constant temperatures for Asian corn borer during the immature stages from newly deposited egg to adult emergence

Table 3 showed a series of developmental linear equations, sigmoid developmental equations, and R^2 values. The minimum and maximum threshold temperatures for each stage or event of Asian corn borer were presented in this Table. The degree-days required for each developmental stage were also included in this Table.

When reciprocals of the duration of each stage of corn borer being reared at constant temperature are plotted against temperature, a S-shaped curve of development, including the approximately linear region of development curve is valid (Matteson *et al.*, 1965). Since gross error in predicted development rates occur at the temperature extremes (Stinner *et al.*, 1974), so the methods for calculating degree days allow for upper and lower thresholds (Allen., 1976; Higley *et al.*, 1986). Presently many studies are the use of linear equations to describe developmental rate, then achieved the lower developmental threshold temperatures. The method has been criticized by a number of researchers (Stinner *et al.*, 1974; Sharpe *et al.*, 1977; Li *et al.*, 1986). They argued that at temperature extremes, developmental velocities did not follow a linear path, but tended to approach a maximum developmental temperature and then decline until mortality occurred. At lower temperatures, insect development slowed, but continued beyond the base temperature predicted by a linear function. If insects would be exposed to extreme temperatures during development prediction periods, functions other than linear equations must be utilized. To capture the nonlinearity of Asian corn borer development for determining the higher limit temperature threshold, a sigmoid function described by Stinner *et al.* (1974) was employed in this study to determine the parameters of degree-day model more accuracy.

The results of laboratory experiment in this investigation revealed the detrimental effects of extreme temperatures on immature development of Asian corn borer, but were otherwise consistent across temperatures, indicating that optimal development occurred between 16℃ and

30℃. However, the velocity line of the combined immature stages varied from the normal at its upper and lower limits, as with the velocity lines of the individual immature.

Table 3 Equations and parameters of Asian corn borer at various constant temperatures

Stage	Theoretical thresholds			Equation④	R^2
	D_L①	D_U②	Degree-days③		
Egg	10.38±0.02	28.0	79.15±5.18	$Y=-0.170857+0.015072X$	0.978
				$Rt=0.226/(1+e^{6.499-0.343T})$	0.956
1st instar	10.88±0.003	32.0	51.90±4.32	$Y=-0.205+0.019X$	0.999
				$Rt=0.337/(1+e^{5.503-0.280T})$	0.922
2nd instar	9.70±0.02	35.0	46.81±2.18	$Y=-0.201+0.021X$	0.986
				$Rt=0.755/(1+e^{3.720-0.136T})$	0.986
3rd instar	10.33±0.03	31.0	42.31±3.94	$Y=-0.250+0.024X$	0.970
				$Rt=0.465/(1+e^{4.523-0.228T})$	0.835
4th instar	10.92±0.008	30.0	49.53±2.41	$Y=-0.233+0.021X$	0.997
				$Rt=0.391/(1+e^{5.391-0.272T})$	0.930
5th instar	10.03±0.006	35.0	136.37±4.16	$Y=-0.076+0.008X$	0.985
				$Rt=0.174/(1+e^{4.434-0.209T})$	0.973
Combined instar	10.06±0.01	32.0	336.73±12.71	$Y=-0.031+0.003X$	0.997
				$Rt=0.065/(1+e^{4.475-0.232T})$	0.997
Pupa	11.07±0.007	31.0	128.82±3.99	$Y=-0.086+0.007X$	0.975
				$Rt=0.155/(1+e^{4.679-0.222T})$	0.945
Egg to adult	10.35±0.02	32.0	539.91±8.62	$Y=-0.01925+0.00186X$	0.998
				$Rt=0.037/(1+e^{5.064-0.253T})$	0.989

①Minimum threshold temperature (℃) determined from the linear equation. ②Upper threshold temperature (℃) determined from the sigmoid equation. ③Degree-days for each developmental stage. ④Y is developmental rate (1/day) of linear equation in Stinner's *et al*. (1974) equation; X is constant temperature. Rt is developmental rate (1/day) of Stinner's *et al*. (1974) equation; T is constant temperature.

There was a decrease in developmental time with increasing temperature for most life stages up to 30℃, above which developmental time increased. The exception was the egg stage, whose developmental time decreased only up to 26℃, after which they increased.

Estimates of minimum development and upper limited thresholds were similar for all developmental stages except the pupae which had a about 1℃ higher than those of other stadia at lower developmental threshold; and eggs which had a about 3℃ lower than other stadia at higher developmental threshold. Averaged over all stadia, a pooled lower developmental threshold was estimated to be 10.35℃. Reports of lower developmental thresholds for other temperate-zone Asian corn borer varied from each other. General speaking, there have not been the reports referring the upper developmental thresholds of Asian corn borer in China.

From this experiment, it might be realized that within limits, for example, 12 to 26℃ in egg stage, 14 to 30℃ in larval stage and pupal stage, higher temperatures produced greater growth rates because reaction proceed more rapidly at higher temperatures. As temperature increase, diffusion rates for substrates or enzymes or both also increase, resulting in greater formation of enzyme/substrate complexes. Additionally, higher temperatures provide more thermal energy for meeting energy requirements of the reaction (Sharpe *et al*., 1977).

Although some approaches for calculating lower developmental threshold are available (Kirk *et al*., 1981), they also produced estimated values. So x-intercept method which employed in this approach was acceptable. Whichever method is used to determine the lower developmental thresholds, thus, in calculating degree-days, invariably introduces some inaccuracy

(Higley *et al*., 1986).

Estimating a upper limited threshold is a challenging because the variability in developmental rates is usually greater at higher temperatures and because mortality is high. Presently available techniques for calculating upper developmental threshold are not precise (Higley *et al*., 1986). Furthermore, most often, developmental maxima were not determined for applying the studies on Asian corn borer. Determine upper limited threshold temperatures in this study attempted to reduce the error induced by lacking upper developmental threshold for calculating degree-days in the investigation of Asian corn borer. This approach in this experiment was in a sense more applicable in the conditions of Yunnan.

Acknowledgments We thank Dr. Manas Titayavan who works in Chiang Mai University, Thailand for reviewing earlier drafts of the manuscript. We express our gratitude to Prof. Yang Ben-li, Prof. Luo You-zhen, Mr. Sun Yue-xian and Mr. Xie Xiao for their technical assistance.

References

Allen J C, 1976. A modified sine wave method for calculating degree days. *Environ. Entomol.*, **5**: 388－396.

Apple J W, 1952. Corn borer development on canning corn in relation to temperature accumulations. *J. Econ. Entomol.*, **45**: 877－879.

Bovin G, Ritchot C, Martel P *et al*, 1986. Evidence for regional differences in the emergence pattern of the Euperan corn borer (Lepidoptera: Pyralidae) in Quebec. *J. Econ. Entomol.*, **79**: 978－980.

Calvin D D, Higgins R A, Knapp M C *et al*, 1991. Similarities in developmental rates of geographically separate European corn borer (Lepidoptera: Pyralidae) populations. *Environ. Entomol.*, **20**: 441－449.

Higley L G, Pedigo L P, Ostlie K R, 1986. DEGDAY. A program for calculating degree-days and assumptions behind the degree-day approach. *Environ. Entomol.*, **15**: 999－1016.

Jarvis J L, Brindley T A, 1965. Predicting moth flight and oviposition of European corn borer by the use of temperature accumulations. *J. Econ. Entomol.*, **58**: 300－302.

Kirk J R Van, Aliniazee M T, 1981. Determining low-temperature threshold for pupal development of the western cherry fruit fly for use in phenology models. *Environ. Entomol.*, **10**: 968－971.

Li D M, Wang R S, 1986. The study of rapid estimating the developmental threshold and degree-day accumulations. *Entomol. Know.*, **23**: 184－187. (in Chinese).

Lin S, Hudson A C, Richards A G, 1954. Analysis of threshold temperatures for the development of Oncopeltus and Tribolium eggs. *Phys. Zool.*, **27**: 287－310.

Lu M R, 1992. Final report of the species and incidence of Asian Corn Borer in Yunnan. (Restricted publication. in Chinese).

Matteson J W, Deeker G C, 1965. Development of the European corn borer at controlled constant and variable temperatures. *J. Econ. Entomol.*, **58**: 344－349.

Miller J C, Paustian J W, 1992. Temperature-dependent development of *Eriopis connexa* (Coleoptera: Coccinellidae). *Environ. Entomol.*, **21**: 1139－1142.

Pedigo L P, 1989. Entomology and pest management. New York: Macmilian Pub.

Sharpe P J H, DeMichele D W, 1977. Reaction kinetics of pokilotherm development. *J. Theor. Bio.*, **64**: 649－670.

Showers W B, Witkowski J F, Mason C E *et al*, 1983. Management of the European corn borer. North Cent. Reg. Publ. No.22. Iowa State Univ., Ames, Iowa.

Stinner R E, Gutierrez A P, Butler G D, 1974. An algorithm for temperature-dependent growth sumulation. *Can. Entomol.*, **106**: 519－524.

Zhou D R, Wang Y Y, Ju Z L, 1980. Studies on the mass rearing of corn borer. *Acta Phytophylacica Sinica.*, **17**: 113－122 (in Chinese).

亚洲玉米螟发育速率与温度关系研究

李正跃 卢美璐
（云南农业大学农学院昆虫学系 昆明 650201）

摘 要 利用10～34℃的9个恒温对亚洲玉米螟 *Ostrinia furnacalis*（Guenee）发育与温度的关系进行了研究。亚洲玉米螟除了在10℃不能发育以外，在其余8种恒温中均可发育，但其死亡率在12℃和34℃中较高。从产卵到成虫羽化，卵期占整个发育过程的17%，幼虫期占57%，蛹期占25%。最低发育起点温度卵期为10.38℃，幼虫期为10.06℃，蛹期为11.07℃。高温限制温度卵期为28.00℃，幼虫期和蛹期均为31.00℃。卵期有效积温为79.15日度，幼虫期为339.73日度，蛹期为128.82日度。从产卵到成虫羽化整个过程的发育起点温度为10.35℃，高温限制温度32.00℃，有效积温为539.91日度。

关键词 亚洲玉米螟，温度发育，发育限制温度，日度
中图分类号 Q969.432.8