Journal of Environmental Sciences Vol.5, No.2, pp. 158 – 168 ISSN 1001-0742

Performances of the cotton bollworm, *Heliothis armigera* (Hübner) at different temperatures and relative humidities

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Abstract— The cotton bollworm, *Heliothis armigera* (Hübner) is an important insect species attacking many crops. Their performances have been examined at temperatures from 15 ℃ to 35 ℃ and relative humidities (RH) between 22.5% and 100%, respectively, in order to assess possible effect of climate in future on its occurrence and infestation. Durations of all developmental stages of the insect shortened with increasing temperature. The temperature favoring population growth ranged from 25 ℃ to 30 ℃ .

Larval duration and adult longevity decreased as relative humidity increased, but development of other stages was independent of RH. At RH of over 64%, their survival rate, egg production and oviposition rate varied a little, and all the population parameters of the insect remained at a relative constant level.

Keywords: cotton bollworm (*Heliothis armigera*); global climate; relative humidity; population parameters.

The global climate warming during the last 100 years has been widely recorded. While there is certain disagreement on temperature-rising magnitude, it is commonly expected that such trend of change in climate will continue hereafter even at greater rate than before, because more and more greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), mathane (CH_4), chlorofluorocarbons (CFCs) and so on mainly produced by various human activities are emitting into atmosphere.

Change in air temperature together with alteration of precipitation, air relative humidity, soil moisture and so on induced by it will exert a substantial influence on agriculture and ecosystems. Insect pests are one of important component parts in ecosystem and their infestation annually makes considerable damage to various crops. These animals are poikilothermal and very susceptible to climatic factors. The cotton bollworm, *Heliothis armigera* (Hübner) widely distributes between 50° N. lat. and 50° S. lat. in the Old World and is a key insect pest, attacking cotton, corn, tomato, beans and so on in China (Hsu, 1958). To assess potential consequence caused by climate change in future to agricultural production, population dynamics of this insect species have been studied at different temperatures and relative humidities in laboratory.

MATERIALS AND METHODS

Insect stock

The colony of the cotton bollworm, *Heliothis armigera* (Hübner) was initiated from older larvae collected in late autumn in Beijing Suburbs. After overwintering in form of diapausing pupae, eggs laid by the adult moth of the first generation in following spring were used to observe effect of temperature on their successive developmental stages, and those of the second one for examining their response to different relative humidities.

Treatments of temperature and relative humidity (RH)

Effect of temperature on the insect was studied in environmental chambers set for the constant temperatures of 15, 20, 25, 30 and 35 ℃, respectively, with a 16:8 photoperiod and about 70% −90% RH. Eggs laid within 6 h were held in 5 ml beaker for hatching. The newly hatched larvae were reared on younger cotton leaves, *Gossypium hirsutum* L. in glass tube (1.5 cm in dia. × 8.0 cm high), 5 individuals per container. Beginning from the 4th instar, the caterpillars were separately fed with middle-matured pod of the bean, *Phaseolus vulgaris* L. in the tube until they pupated. The food material was renewed daily. After eclosion, couples of moths were separately confined in lamb chimney (10cm in dia. × 10 cm high) on a jar containing some water, and 10% bee honey solution was supplied as their food.

Performances of the cotton bollworm at different RH were observed in desiccator (20 cm in dia. × 30 cm high) at 25 ℃ with a 14:10 photoperiod. Saturated solution of CH_3COOK, NaI, $NaNO_2$ and KBr was used to create 22.5%, 38%, 64% and 80% RH, respectively (Winston, 1960), and distilled water to maintain the saturated humidity.

Procedure of rearing the insect was similar to that for the test with temperature. The main differences from the former are as follows: The tube was open at both ends and covered by fine-mesh nylon screen during egg and younger larval stages, and by 80-mesh brass screen after 3rd instar; the food plant offered was so small that it was almost exhausted after a day's interval; the moths in chimney was exposed to specific RH.

Collection and analysis of data

Time taken by eggs to hatch and the dates on which the larvae moulted and pupated as well as adults emerged were recorded. Stage-specific survival schedule of immature stage and age-specific fecundity schedule of adult moth were monitored.

These data were used to calculate index of population trend which is multiplication of egg number after one generation and other population parameters, i.e. the net rate of reproduction (R_0), the intrinsic rate of increase (r_m), the finite rate of increase (λ) and the mean length of generation (T) according to the definition and formulas given by Birch (1948) and Andrewartha *et al.* (1954).

RESULTS AND ANALYSES ON EFFECT OF TEMPERATURE

Development of immature stage

Time required from egg to adult varied between 122.6 days at 15 ℃ and 22.5 days at 35 ℃. The durations of female individuals were a little shorter than that of males at all the temperatures tested. Durations of egg, larvae and pupae decreased exponentially as temperature increased (Fig. 1).

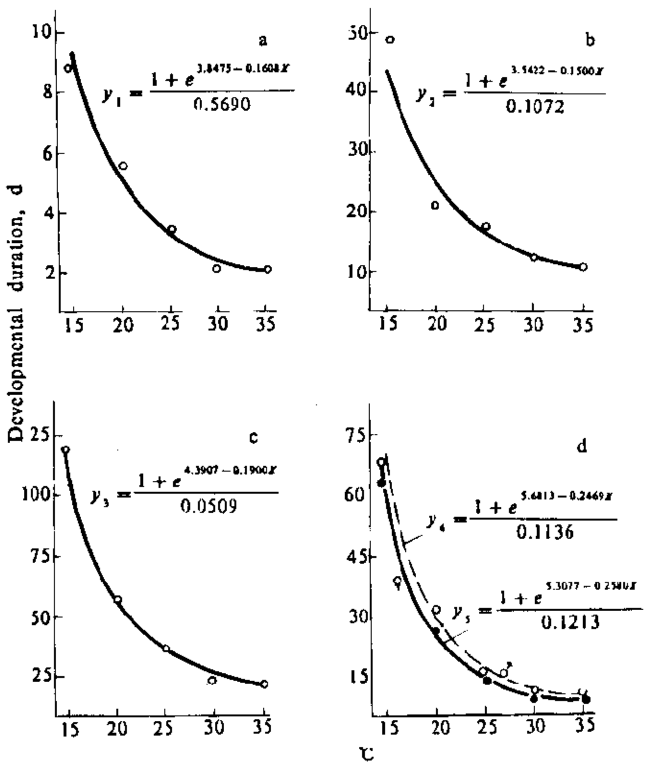

Fig. 1 Developmental duration of the cotton bollworm in relation to temperature

a —egg; b —larva; c —egg to adult (female); d —pupae

Based on the durations of various stage, the low threshold temperatures calculated to initiate development of the insect species is the highest for pupae and the lowest for larvae (Table 1). The accumulated thermal requirement for whole immature stage is estimated to be about 500 day-degree above 11 ℃ .

Table 1 Low threshold temperature and accumulated thermal requirement for the cotton bollworm

Stage	Egg	Larvae	Pupae		Egg-adult
			Female	Male	
Low threshold temperature, ℃	10.11	8.36	12.70	12.95	10.87
Accumulated thermal requirement, d-d[1]	49.1	285.9	173.9	186.8	505.0

[1] day-degree

Survival of immature stage

Egg mortality exceeded 30% at 15 ℃ and 35 ℃ , showing adverse effect of low or high temperature on its hatching. Lower survival rate of older larvae and pupae also occurred at 15 ℃ , but not at 35 ℃ (Table 2).

Table 2 Survival rate of the cotton bollworm at different temperatures

Temp., ℃	15	20	25	30	35
No. egg tested	100 × 3	100 × 3	100 × 3	100 × 3	100 × 3
Hatching, %[1]	69.5	72.0	85.7	72.9	55.2
No. larvae tested	100	100	100	100	100
Survival, %					
1st-3rd instar	95.0	95.0	96.0	94.0	94.0
4th-6th instar	60.0	80.0	80.2	95.7	92.6
Pupae	75.4	86.8	85.7	94.4	92.0

[1] Mean value of 3 determinations.

Survival rate from egg to adult increased gradually at 15 ℃ up to 30 ℃ and then declined at 35 ℃ , but still much higher than that at 15 ℃ . The relationship between survival rate of whole immature stage and temperature was illustrated in Fig. 2. According to the curve fitted, the highest survival rate, 59.7%, was predicted to occur at about 27 ℃ .

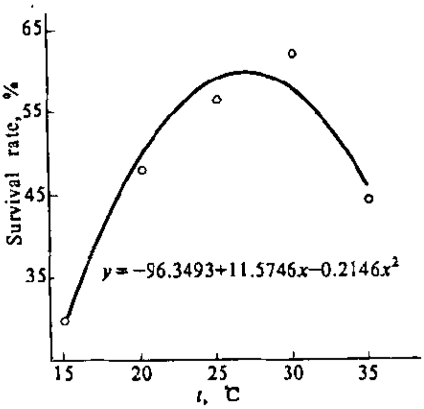

Fig. 2 Survival rate of immature stage of the cotton bollworm in relation to temperature

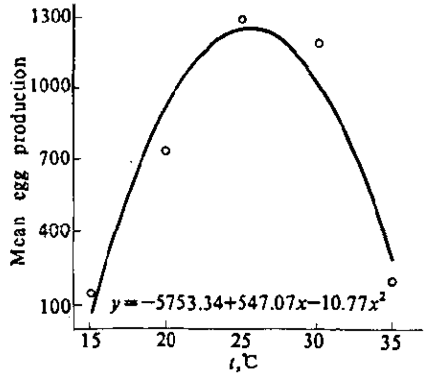

Fig. 3 Effect of temperature on egg production by *H. armigers* adult

performance of adult moth

To observe their performances, 10−13 pairs of moths were examined, depending on stock of the adult from different groups. Both egg production (mean of eggs laid per female) and oviposition rate (% egg production in total eggs, including those laid and remained in the body of died moth) were greatly affected by temperature. The maximum egg production of over 1250 was recorded at 25 ℃ and the minimum of ca. 150 at 15 ℃ . Fig. 3 describes the relationship between mean egg production and temperature.

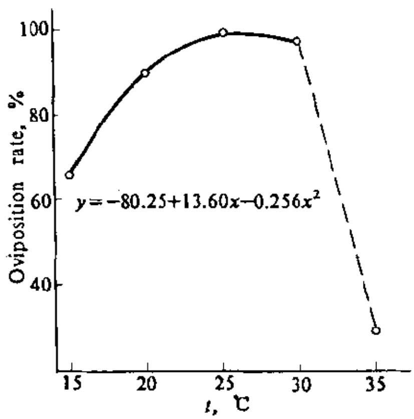

Fig. 4 Percent oviposition of adult moth of the cotton bollworm at different temperatures

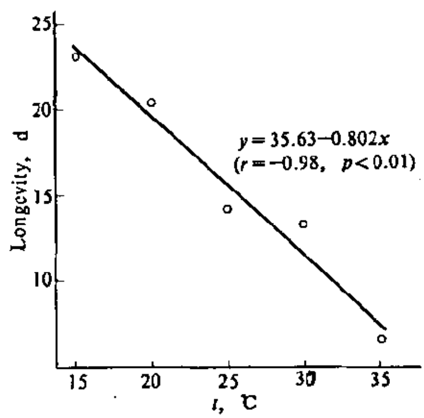

Fig. 5 Adult longevity of the cotton bollworm in relation to temperature

Oviposition rate increased at 15℃ through 30℃, and then sharply dropped to ca. 30% at 35℃, much lower than that at 15℃ (Fig. 4).

Life-spans of both female and male moths shortened linearly with rising temperature. Since no significant differences were detected between sexes at each of temperatures, their longevities were pooled and plotted against temperature in Fig. 5.

Index of population trend

Based on survival rate and mean egg production, indexes of population trend of the cotton bollworm at 5 temperatures were calculated and shown in Fig. 6. Obviously, a parabolic relationship exists between them. According to the equation fitted, the maximum index was estimated as 353 at 25.56℃ and the population size would keep unchanged at 15.03℃ or 36.09℃ from generation to generation.

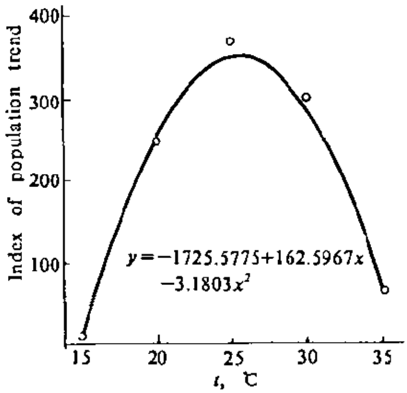

Fig. 6 Index of population trend of cotton bollworm in relation to temperature

EFFECT OF RELATIVE HUMIDITY

Duration of immature stage

Egg and pupal development was little affected by RH (Table 3) whereas larval duration shortened as RH increased and a linear equation was established between them (Fig.7). The duration of whole immature stage also decreased with increasing RH, apparently resulting from its influence on larval development.

Table 3 Durations of the cotton bollworm at different relative humidities

(Unit: day)

RH, %	22.5	38.0	64.0	80.0	100
Egg	3.84±0.03	3.79±0.03	3.72±0.03	3.68±0.02	3.75±0.02
Larvae	26.0	24.08±0.31	21.70±0.17	20.83±0.43	19.38±0.26
Pupae:					
Female	–	16.31±0.24	16.61±0.26	16.47±0.23	17.00±0.36
Male	–	17.67±0.28	18.12±0.24	18.11±0.32	18.12±0.19

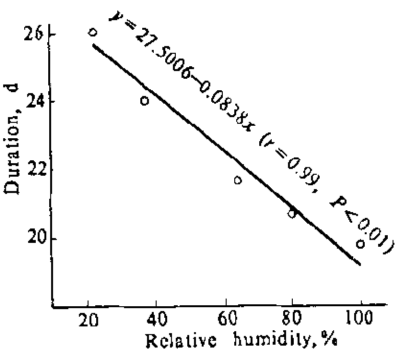

Fig. 7 Larval duration of the cotton bollworm in relation to relative humidity

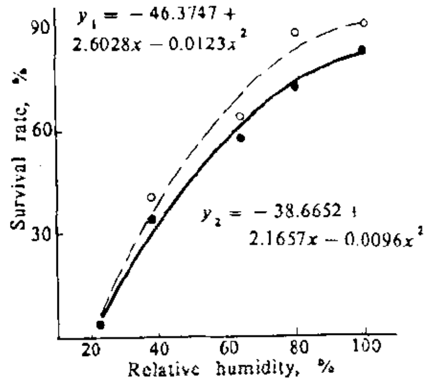

Fig. 8 Effect of relative humidity on survival of *H. armigera* larvae

1—first instar; 2—total larval stage

Survival of immature stage

Egg mortality varied between 8% and 15% (Table 4) and it seems unlikely that such variation was related to ambient humidity. 22.5% RH caused heavy mortality of the larvae. In this group, only 3% of the caterpillars survived prepupal stage and all of them died during pupal stage. Lethal effect of the extreme RH on larvae mainly occurred during their first instar, whose survival rate increased as RH increased (Fig. 8). Survival curve of total larval stage at RH tested was similar to that of the first instar except having a little lower survival rate at higher RH (Fig. 8).

In contrast to larval stage, the pupae from the larvae exposed to lower RH showed higher survival rate at the same RH (Table 4). As a result, survival rate of egg-adult increased from 23.4% at 38.0% RH to 38.7% at 64.0% RH, and then remained at a relative constant level at higher RH.

Table 4 Survival rate of the cotton bollworm at different relative humidities

RH, %	22,5	38.0	64.0	80.0	100
No. eggs tested	80×3	80×3	80×3	80×3	80×3
Hatching, %[1]	91.6	85.1	89.9	90.3	89.0
No. larvae tested	100	100	100	100	100
Survival rate, %					
1st-3rd instar	4.0	34.0	61.0	80.0	87.0
4th-6th instar	75.0	100	95.1	90.0	95.4
Pupae	0	79.4	74.1	59.7	53.0

1. Mean value of 3 determinations

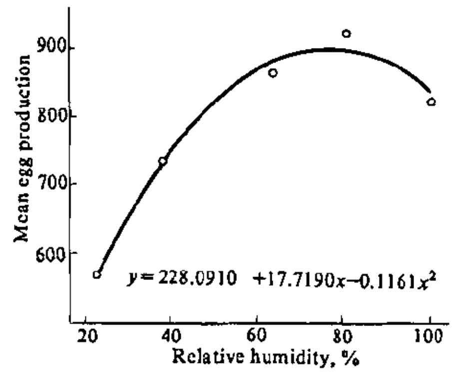

Fig. 9 Effect of relative humidity on egg production by female moth of the cotton bollworm

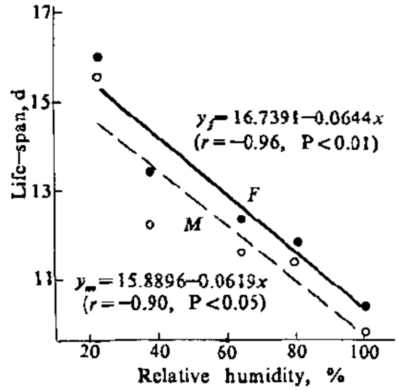

Fig. 10 Adult life-spans of cotton bollworm in relation to relative humidity
F –female M –male

Performance of adult moth

Since no moth emerged at 22.5% RH, some pupae from stock culture kept at 25 ℃ in room were exposed to this RH. After eclosion, the moths' performance was examined at the same humidity.

Table 5 Population parameters of the cotton bollworm at different temperatures and relative humidities

Parameter[1]	r_m	R_0	λ	T	IPT
Temp, ℃					
15	0.0225	18.89	1.023	130.61	8.8
20	0.0786	170.72	1.081	65.39	225.8
25	0.1451	350.56	1.156	40.38	364.0
30	0.1902	347.25	1.210	30.76	295.5
35	0.1368	38.03	1.147	26.60	62.9
RH, %					
22.5	–	–	–	–	–
38.0	0.0713	42.42	1.074	52.56	90.3
64.0	0.0911	84.71	1.095	48.73	179.1
80.0	0.0923	90.11	1.097	48.76	183.0
100	0.0945	81.20	1.099	46.53	167.0

[1] r_m–intrinsic rate of increase; R_0–net rate of reproduction; λ–finite rate of increase; T–mean length of generation; IPT–index of population trend.

Egg production by the moths was significantly affected by RH, but thier oviposition rate was not. Mean egg production increased in proper order at 22.5% RH through 80% RH, and then decreased to some extent at saturated humidity, which was much greater than that at the lowest RH (Fig. 9). Oviposition rate varied between 93.8% and 96.7% with an overall mean of 95.1% at 5 humidities.

Apparent effect of RH on life-spans was also observed. The higher the relative humidity, the shorter the longevity of the moth. Between them there was a significant linear relationship (Fig. 10).

Index of population trend

At 22.5% RH, the cotton bollworm failed to complete its generation circle, and all the population parameters was unavailable (Table 5). Exposure to 38% RH resulted in small index of population trend, only about half of the greatest one occurring at 80% RH. However, the index did not vary much at over 64% RH with an overall mean of 176.4.

POPULATION PARAMETERS

The population parameters calculated based on above-mentioned results of experiments at different temperatures and relative humidities are presented in Table 5. Most of the parameters became greater rapidly with increasing temperature up to 25 ℃ and reached their maximum values at 25 ℃ or 30 ℃, and then sharply declined at 35 ℃. The mean generation length (*T*) shortened successively as temperature increased. Lower than 40% RH strongly depressed growth of *Heliothis armigera* population, and even killed all the individuals while all the population parameters varied a little at humidities ranging from 64% to 100%.

DISCUSSION

The results from rearing experiments in laboratory showed that both temperature and relative humidity had substantial influence on population dynamics of the cotton bollworm, but they acted in different ways. Developmental time of all life stages of the insect species shortened as temperature increased whereas only larval duration and adult longevity were significantly affected by humidity.

At high or low temperature, percent survival of immature stage and fecundity of adult moth markedly declined. Thus, the temperature favoring population growth of the insect ranges from 25 ℃ to 30 ℃, which is in fairly agreement with that reported by Gelusenkef (1955). He stated in the same paper that no egg was laid by the female moth below 20 ℃. However, we did observe that the moth was able to deposit eggs even at 15℃, although their fecundity was poor. This disparity could be the result of genetic difference between the stocks of the insect originated from different geographical zones. The maximum mean egg production recorded in the present test was about 1300, which falls in the range between 960 for the first generation and 1825 for the 2nd one observed by Shu *et al.* (1958).

The extreme low RH had little impact on egg-hatching, but caused heavy mortality of the neonate larvae, resulting in failure of its generation circle. At 64% RH through saturated humidity, survival rate during immature stage and egg production by female moth varied a little. As a result, relatively constant population parameters had been obtained.

It can be seen from Table 5 that most of population parameters of the cotton bollworm at 25℃ and 70%–90% RH in the test of temperature series are much greater than those in experiment of humidity series under similar condition. Poorer performance of insects in the latter case was frequently found in literature and usually attributed to lack of good ventilation in such closed container.

Temperature, humidity light and gases have been recognized for long time as the 4 basic physical factors on which abundance of insect populations depends. Among them, effect of temperature has comprehensively and intensively been studied with numerous insect species as objects while humidity playing role in insect life was only investigated in some cases, and most species examined in such test are those infesting stored products such as grain beetle (Arbogast, 1976; Kawamoto, 1990), flour beetle (Imura, 1984; Saleem, 1985), grain weevil (Okelana, 1985) and so on. Generally, these species of insects performed best within a medial regime of humidity, 50%–75% RH, with certain tolerance to low humidity. But potential of population growth was greatly depressed at over 90% RH. For example, two species of sawtoothed grain beetles were unable to complete their development at 96% RH (Arbogast, 1976).

Two recent papers dealing with relationship between phytophagous insect and relative humidity were reported by Patil *et al.* (1984) for the teak defoliator, *Pyrausta machoeralis* and by Majeed *et al.* (1985) for the hopper, *Gastrimargus transversus*. Both the insect species enjoyed higher humidity and heavier mortality of the hopper occurred when exposed to extreme low or high RH.

Similarly, *Heliothis armigera* performed best at about 27℃ and 80% RH. However, saturated humidity did not show significant adverse effect on it.

It should be pointed out that fresh plant material provided as larval food and its replace daily may fluctuate RH for a time in the closed container, which could affect accuracy of results observed to some extent. This kind of error is hard to be avoided in the experiments such as reported in this paper and by other authors. Nevertheless, general trend of population dynamics of the cotton bollworm at different relative humidities is apparent.

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(Received April 28, 1992)