Article

Development - temperature relationship and temperature dependent parameters of German cockroach, *Blattella germanica* L.

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Received 16 November 2015; *Accepted 26 January 2016*; *Published 1 September 2017*

Abstract
German cockroach, *Blattella germanica* L., is one of the most health pests around the world. Development-temperature relationship and temperature-dependent parameters of *B. germanica* were determined in present study. The experiment was conducted in the incubators with five constant air temperatures, 23℃, 28℃, 31℃, 36℃, and 40℃. The photoperiod of 16 h light / 8 h dark and the relative humidity of 74%-76% were fixed for all incubators. Three replicates were set for each temperature. Based on linear regression equations, the estimated starting temperature for development of 1st to 5th instar nymphs of *B. germanica* is 14.26±3.157, 13.70±2.284, 14.59±3.575, 16.58±2.398, and 18.47±1.442 ℃, respectively. The estimated effective accumulated temperature of 1st to 5th instar nymphs is 99.18±19.68, 97.01±13.47, 92.06±21.17, 80.26±9.784, and 64.06±9.784 d℃ (day degrees), respectively. *B. germanica* had the highest survivorship and hatching rate, and the least instars for eclosion and hatching time, around 31℃, which is the optimum temperature range for development and survival of *B. germanica*. *B. germanica* could not survive at 40℃. Even at 36℃, all eclosed adults had vestigial wings and could not normally mate and reproduce.

Keywords *Blattella germanica*; effective accumulated temperature; starting temperature for development; developmental rate; life table; survivorship.

Arthropods
ISSN 2224-4255
URL: http://www.iaees.org/publications/journals/arthropods/online-version.asp
RSS: http://www.iaees.org/publications/journals/arthropods/rss.xml
E-mail: arthropods@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

German cockroach, *Blattella germanica* L., is a species of one-quarter size of most cockroach adults. *B. germanica* reproduces rapidly. It may carry various pathogenic bacteria and virus in the body and transmit diseases by foraging foods in human residents. Diseases caused by cockroach include hepatitis B, bowel membrane inflammation, asthma, diarrhea, cold, etc. It is one of the most important health pests around the world. *B. germanica* originated from Africa and distributes widely all over the world. In China, it can be found in most provinces and regions. So far, some ecological research has been conducted on cockroaches.

Diekman and Ritzmann (1987) investigated the effect of temperature on flight initiation in the cockroach *Periplaneta americana*. Tsai and Chi (2011) described the temperature-dependent demography of *Supella longipalpa*. Zhu et al. (2006) analyzed the effects of photoperiod and temperature on nymphal development and adult reproduction in the forest-dwelling cockroach. Zhu and Tanaka (2004) explored the photoperiodism and temperature affect the life cycle of a subtropical cockroach, *Opisoplatia orisoplatia*. In addition, various research were conducted in terms of life tables, diapauses, overwintering, and transduction of the vitellogenic signal of juvenile hormone, etc., of cockroaches (Enescu and Balazs, 1972; Brown, 1973, 1980; Tanaka and Uemura, 1986; Shindo and Masaki, 1995; Aguilera et al., 1997; Tanaka and Zhu, 2003; Qi and Sun, 2004; Naghdi et al., 2016).

So far, there are not detailed studies on development - temperature relationship and parameters of *B. germanica*. In present article, we report our experimental results on development-temperature relationship and temperature-dependent parameters of *B. germanica*.

2 Materials and Methods

2.1 Experiment

Collected adults were placed inside a single plastic bottle (200ml) without cover. Some Vaseline was plastered along the bottleneck to prevent them from escaping. In addition, a plate of about 2cm-diameter and 1cm-high was placed inside each bottle to provide water. Water was added at regular intervals and food (SPF mouse feed, made in Guangdong Medical Lab Animal Center; mechanically grind and screen by mesh 100×100 for use) was supplied at an interval of 2d. Three bottles were placed in each of five incubators with constant air temperatures, 23℃, 28℃, 31℃, 36℃, and 40℃, with the error of ±0.5℃. Constant photoperiod of light: dark=16 h : 8 h is used in all incubators. And the relative humidity in each incubator is set to about 74%-76%. Once adults oviposit eggs, eggs were kept in the bottle and adults were removed. After the nymphs were hatched, record the hatching time, and rear them in a bottle with the same size, food/water supply, photoperiod/humidity and temperature. About 40-50 nymphs were kept in each bottle. Developmental duration (*N*) and survivorship of every stage were observed between 17:00 and 19:00 every day. Nymphs were labelled by yellow or green paint on their back to determine whether they have molted. New adults were recorded and removed from the bottle.

2.2 Analytical method

Known $K=N*(T-C)$, where C is starting temperature for development, and K is effective accumulated temperature (K). We used the Direct Optimal Method (Li and Wang, 1986) to calculate the starting temperature for development and effective accumulated temperature, as indicated in the following

$$T = C + \frac{K}{N} = C + KV \qquad V=1/N$$

$$C = \frac{\sum V^2 \sum T - \sum V \sum VT}{n\sum V^2 - (\sum V)^2} \qquad K = \frac{n\sum VT - \sum V \sum T}{n\sum V^2 - (\sum V)^2}$$

$$Sc = \sqrt{\frac{\sum (T-T')^2}{n-2}\left[\frac{1}{n} + \frac{\bar{V}^2}{\sum (V-\bar{V})^2}\right]} \qquad S_K = \sqrt{\frac{\sum (T-T')^2}{(n-2)\sum (V-\bar{V})^2}}$$

where N is developmental duration (d), n is number of datasets, T is observed temperature (℃), T' is calculated temperature, V is developmental rate (1/d; V=1/N), $\bar{V}$ is averaged developmental rate. S_c and S_k are standard errors of C and K respectively.

3 Results

3.1 Developmental duration and developmental rate

Developmental duration (*N*) and rate (*V*) of *B. germanica* under different temperatures are listed in Table 1. At 40℃, all individuals of *B. germanica* died.

Table 1 Developmental duration (*N*) and rate (*V*) of *B. germanica* under different temperatures.

Instar	23℃		28℃		31℃		36℃	
	N (d)	*V* (1/d)	*N* (d)	*V* (1/d)	*N* (d)	*V* (1/d)	*N* (d)	*V* (1/d)
Egg	N/A	N/A	21.20±1.032	0.0472	15.85±1.875	0.0631	N/A	N/A
1st	12.48±3.115	0.0801	6.313±1.422	0.1584	5.845±1.752	0.1711	4.874±0.9460	0.2052
2nd	11.26±3.714	0.0888	6.328±1.307	0.158	5.243±1.562	0.1907	4.676±1.605	0.2139
3rd	12.11±5.414	0.0826	5.782±0.9560	0.1730	5.479±1.404	0.1825	4.762±1.701	0.2100
4th	12.84±5.385	0.0779	6.509±1.671	0.1536	5.873±1.274	0.1703	6.000±2.194	0.1667
5th	14.67±4.985	0.0682	6.280±1.720	0.1592	5.333±1.129	0.1875	7.050±2.782	0.1418
6th	11.56±4.350	0.0865	6	0.1667	N/A	N/A	8.400±5.039	0.1190
7th	11.44±4.246	0.0874	N/A	N/A	N/A	N/A	12.00±8.185	0.0833

At 40℃, all individuals of *B. germanica* died.

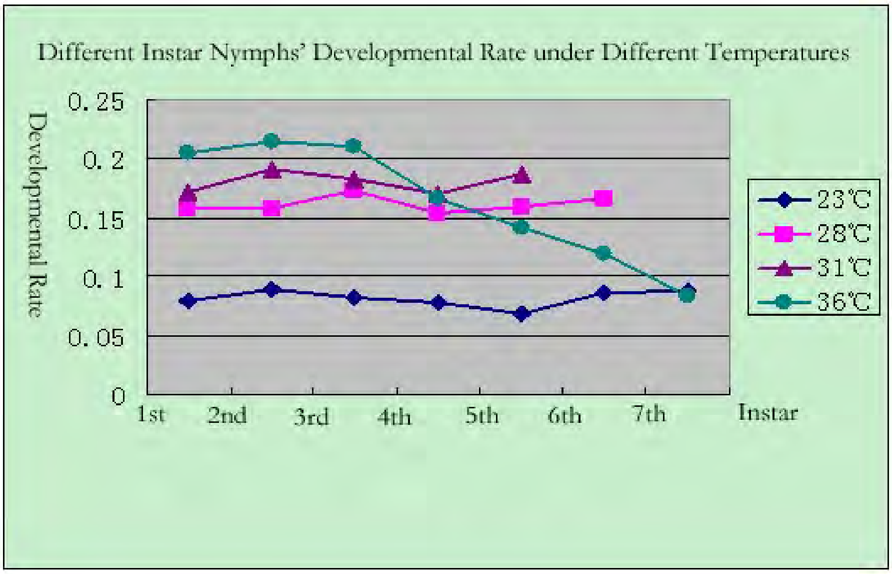

Fig. 1 Comparison of developmental rates between differenct stages under different temperatures.

According to Table 1 and Fig. 1, the influences of temperature on the developmental rate of 1^{st}-5^{th} nymph instars are basically identical under the temperature between 28℃ and 31℃. At the higher temperature, the influences of temperature change considerably as nymph instars.

3.2 Starting temperature for development and effective accumulated temperature

According to Table 1, the developmental duration of each stage declines as the rise of temperature (Fig. 2). At the higher temperature, the duration of some stages, e.g., the developmental duration of 4^{th} instar and 5^{th} instar nymphs increases again. For these stages, the optimal temperature for surviving is less than 36℃.

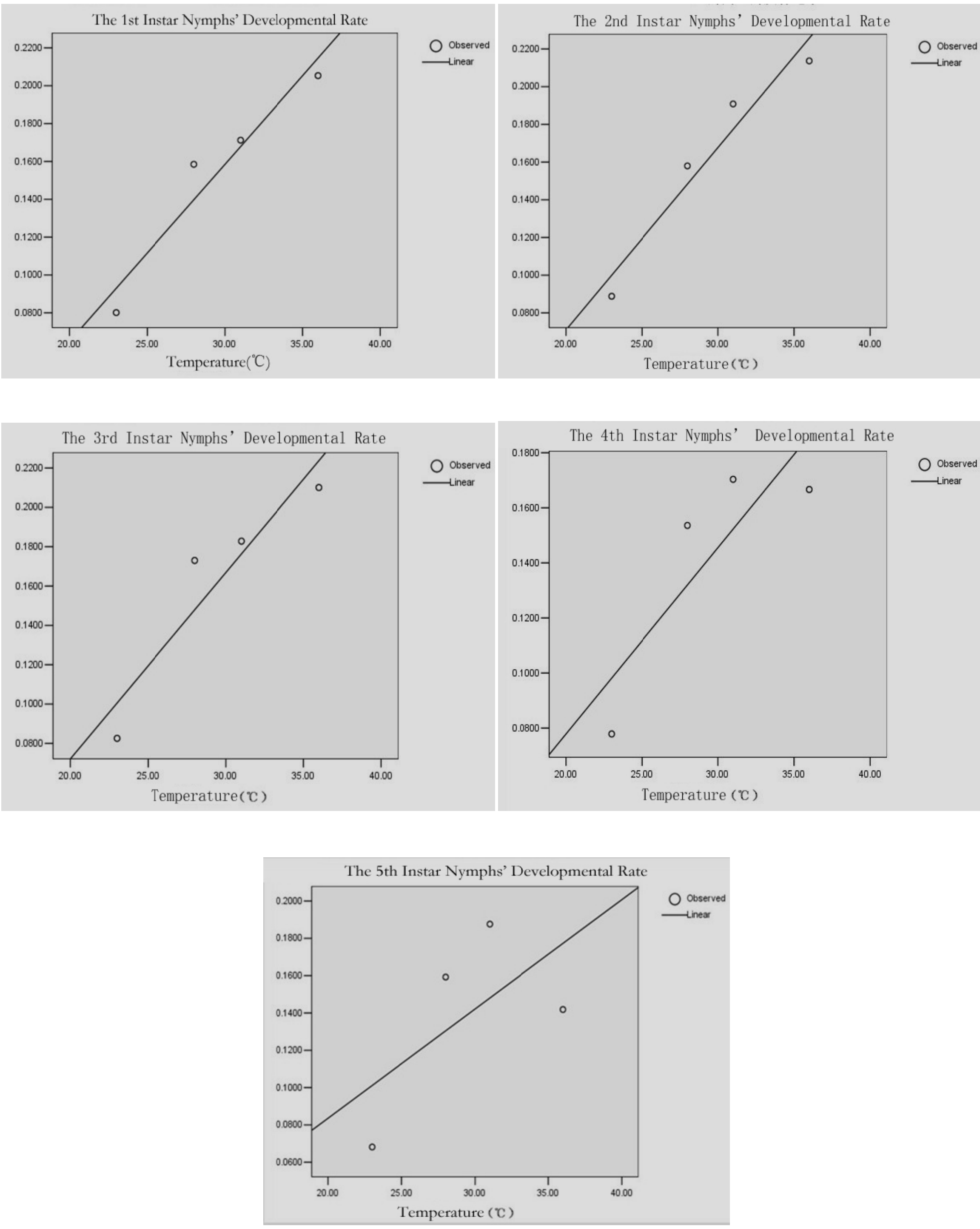

Fig. 2 Relationship between temperature and developmental rate of *B. germanica* under different temperatures.

Therefore, we removed the developmental rates of 4^{th} instar and 5^{th} instar nymphs at 36℃ and 40℃ from the data, and used the method above to estimate starting temperature for development (*C*) and effective accumulated temperature (*K*). The results are shown in Table 2, in which the results for egg, the 6^{th} instar and 7^{th} instar nymphs are absent because their starting temperature for development and effective accumulated temperature could not be calculated.

Table 2 Starting temperature for development and effective accumulated temperature of *B. germanica*.

Instar	Starting temperature for development *C* ℃	Effective accumulated temperature *K* ℃	Regression equation between developmental rate *V* and temperature *T*
1st	14.26±3.157	99.18±19.68	$V = 0.009300T - 0.1220$ ($r^2 = 0.9270$)
2nd	13.70±2.284	97.01±13.47	$V = 0.009700T - 0.1228$ ($r^2 = 0.9394$)
3rd	14.59±3.575	92.06±21.17	$V= 0.009500T - 0.1173$ ($r^2 = 0.8715$)
4th	16.58±2.398	80.26±9.784	$V = 0.01190T - 0.1918$ ($r^2 = 0.9563$)
5th	18.47±1.442	64.06±9.784	$V = 0.01530T - 0.2787$ ($r^2 = 0.9772$)

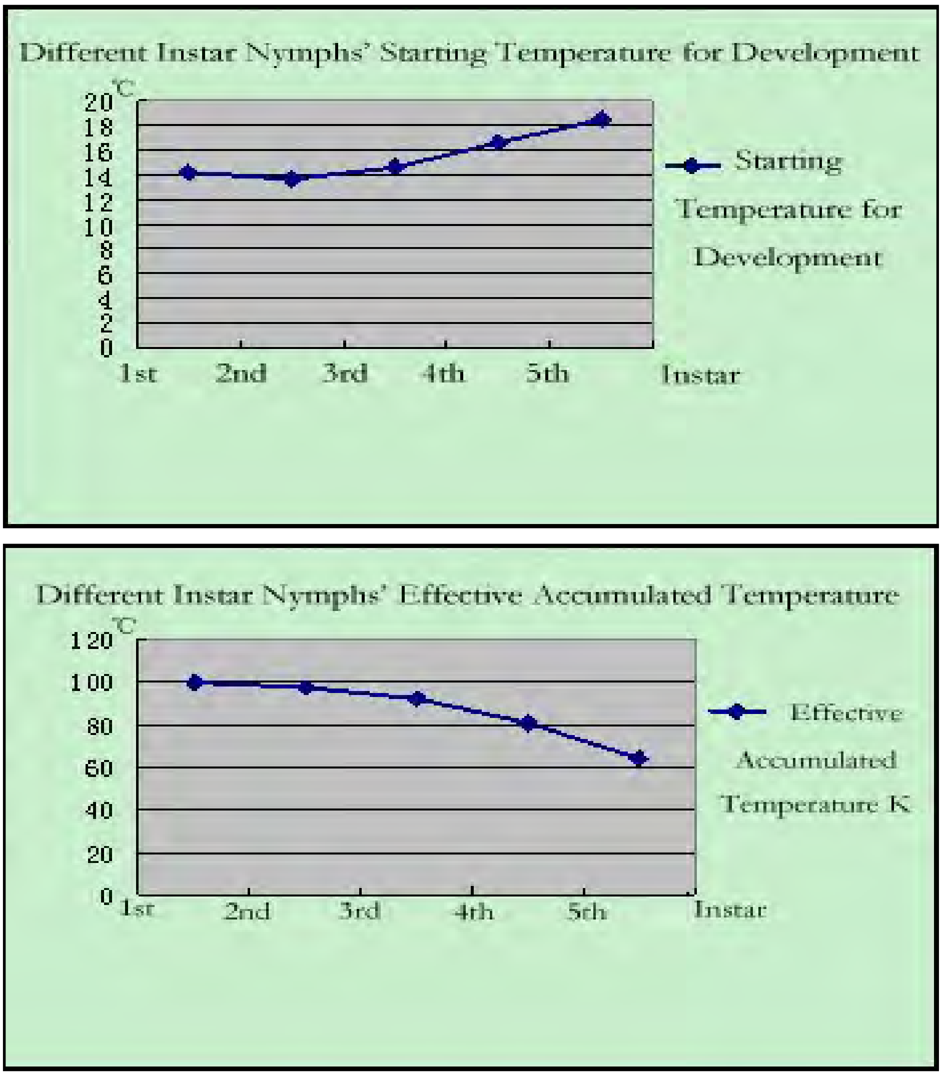

Fig. 3 Changes of starting temperature for development and effective accumulated temperature as nymph instars.

As indicated in Table 2 and Fig. 3, generally the starting temperature for development increases as nymph instars. On the other hand, the effective accumulated temperature declines as nymph instars.

3.3 Life table, survivorship, hatching rate, and hatching time

The life table of *B. germanica* is shown in Table 3.

Table 3 Life table of *B. germanica* in different temperature.

Instar	23℃	28℃	31℃	36℃
1st	161	157	194	169
2nd	63	83	116	103
3rd	46	67	103	74
4th	44	55	94	63
5th	38	53	79+9 eclosion	55
6th	33+4 eclosion	25+26 eclosion	24+54 eclosion	40+8 eclosion
7th	16+17 eclosion	1+19eclosion	24eclosion	15+15 eclosion
8th	9+7 eclosion	1eclosion		3+6eclosion
9th	9 eclosion			

According to Table 3, we get the survival rates of different nymph instars, as indicated in Table 4. Table 4 shows that the survivorship of *B. germanica* is the highest around 31℃.

In the optimum range of temperature, i.e., around 31℃, most nymphs eclosed just after 6th instar or even after 5th instar. However, under the lower or higher temperature, most nymphs eclosed just after 7th instar or even 8th instar.

Table 4 Survival rates of different nymph instars.

Instar	23°	28°	31°	36°
2nd	39.13%	52.86%	59.79%	60.94%
3rd	73.01%	80.72%	88.79%	71.84%
4th	95.65%	82.08%	91.26%	85.13%
5th	86.36%	96.36%	93.61%	87.30%
6th	97.36%	96.22%	98.86%	87.27%
7th	100.00%	90.19%	100.00%	79.16%
8th	100.00%	100.00%	N/A	84.21%
Adult	100.00%	N/A	N/A	N/A
Total	22.98%	29.29%	44.84%	18.93%

Hatching rate is higher and hatching time is shorter at temperature 31℃ than 28℃ (Fig. 4).

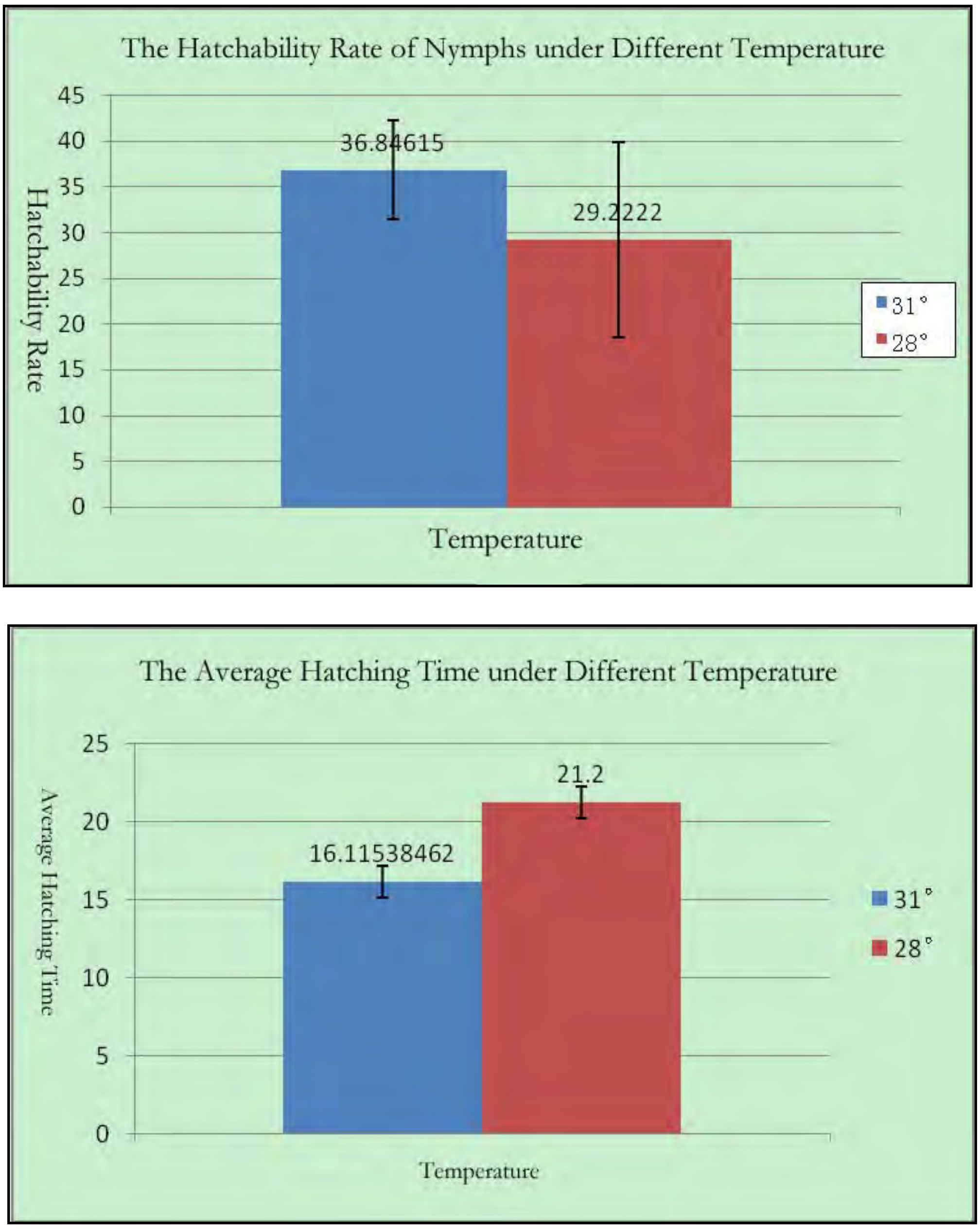

Fig. 4 Hatching rate and time under different temperatures.

4 Discussion

Normally, the optimum temperature for survival of *B. germanica* was considered as 28℃. Our work, however, found that 31℃ is more suitable than 28℃, in terms of developmental rate, survivorship, reproduction, etc.

B. germanica does not adapt to the extreme high temperature. Our experiment found that under the temperature of 36℃, all eclosed adults have vestigial wings. Moreover, they could not mate and reproduce at the temperature, possibly due to lack of expression of some genes, or the expressed proteins cannot function in such a high temperature.

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