第 25 卷第 1 期
2005 年 1 月

生 态 学 报
ACTA ECOLOGICA SINICA

Vol. 25, No. 1
Jan., 2005

温度对卷蛾分索赤眼蜂种群参数的影响

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摘要：通过组建卷蛾分索赤眼蜂 *Trichogrammatoidea bactrae* Nagaraja 在米蛾 *Corcyra cephalonica* (Stainton)卵上实验种群生命表的方法，考察了梯度恒温 17、20、23、26、29、32℃和 35℃对该蜂发育、存活和繁殖的影响。在试验温度范围内，卷蛾分索赤眼蜂的世代发育历期随着温度的升高而缩短，发育历期由 17℃时的 20.77d 降至 35℃时的 7.25d。卷蛾分索赤眼蜂的临界发育温度为 11.92 和 38.95℃，适宜的生长发育温区则介于 20～29℃之间，最适发育温度为 23.07℃。在适宜温度(20～29℃)范围内，卷蛾分索赤眼蜂的幼期存活率维持在 90%以上，雌成蜂具有较长的寿命，7.67～10.87d；内禀增长率(r_m)及净生殖力(R_0)，分别介于 0.2395～0.4890 和 42.32～64.23 之间。极端温度对卷蛾分索赤眼蜂的生长发育和生殖均有明显的抑制作用，在 35℃时，其幼期存活率为 12.98%，雌成蜂寿命不足 1d，且不能进行正常的生殖活动。温度对卷蛾分索赤眼蜂的子代性比有着显著的影响，在 17～35℃范围，子代雌雄性比随着温度的升高而不断下降，17，20，23，26，29℃和 32℃时的子代雌雄性比分别为 6.73，3.48，2.88，2.45，2.41 和 1.75，温度与子代性比的作用关系可用公式 $s=\exp(3.51-0.10\times T)$来表达。

关键词：卷蛾分索赤眼蜂；温度；生命表；性比

Effect of temperature on the population parameters of *Trichogrammatoidea bactrae* Nagaraja

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Abstract: *Trichogrammatoidea bactrae* Nagaraja is a common indigenous natural egg parasitoid of the diamondback moth (DBM) in South China. It has been identified as the most suitable candidate to control DBM in laboratory studies in recent years. However, compared to *Trichogramma* little was known about the biology and ecology of the *Trichogrammatoidea*. In this paper the effects of seven constant temperatures on the reproductive potential of experimental populations of *T. bactrae* Nagaraja parasitizing eggs of *Corcyra cephalonica* (Stainton) was analyzed through life tables.

In our experiment eggs of *C. cephaloica* were glued on paper cards (40mm×50mm) and were exposed for 1-hour to UV-Sterilization treatment. Each egg card was put inside a vial of size 32 mm×100 mm and exposed to the adult parasitoids for half hour at 26 ℃. The vials were then placed in each of seven constant temperature cabinets at (17±1), (20±1), (23±1), (26±1) (29±1), (32±1)℃ and (33±1) ℃, 14 : 10 (L : D) photoperiod and relative humidity 75 %. Development times from egg to adult, survival rates of immatures during development and emergence numbers each day were recorded. Thirty-fifty newly emerged and mated females 12-hours old from each temperature treatment were confined individually in 11 mm × 55mm vials and were exposed to the same constant temperatures. Sufficient numbers of host eggs (n>200 per female) were provided to the parasitoids every day. Daily fecundity, longevity of adults and sex ratio (females/males) of offspring were recorded. During the experiment 25% honey solution was stuck on the wall inside the vial to provide the parasitoids with nutrients. There were 3 replicates for each treatment.

基金项目：国家自然科学基金资助项目(39870439；39930120；39870441)

收稿日期：2003-11-25；**修订日期**：2004-09-19

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Foundation item: National Natural Science Foundation of China (No. 39870439, 39930120, 39870441)

Received date: 2003-11-25; **Accepted date**: 2004-09-19

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Development time of the immature stages decreased with an increase of temperature, 20.8d at 17℃ to 7.2 d at 35℃. The minimum and maximum temperatures for *T. bactrae* development were 11.9 and 38.9℃, respectively. Favorable temperature ranges for development and reproduction of *T. bactrae* were 20～29℃, with an immature survival rate above 90%. The most suitable temperature for population increase was 23.1℃. The intrinsic increase rate (r_m) increased with temperature until a maximum of 0.4890, at 29℃, then dropped dramatically with a continuously rising temperature declining to zero at 35℃. Both longevity of adult females and net reproduction rates (R_0) reached their peaks at 23℃, with values of 10.9 d and 64.2, respectively. However, extreme temperatures greatly restricted population increase of *T. bactrae*. The immature survival rate was only 12.9% at 35℃, and the adult female could live no more than one day even with honey and hosts. Reproductive activity was also greatly affected at high temperatures, the fecundity of adult wasps was 6.1 eggs per female at 32 ℃, and no egg was laid successfully at 35℃. Temperature also has a remarkable influence on the sex ratio of *T. bactrae* progeny. The sex ratio of female to male dropped with increasing temperature. Of the experimental temperatures, the highest female to male sex ratio, 6.7, was observed at 17℃, 3.5, 2.9, 2.5, 2.4 and 1.8 were detected at 20, 23, 26, 29 and 32℃, respectively. The relationship between the sex ratio of offspring and temperature is described by the following formula $S=\exp(3.51 \sim 0.10 \times T)$.

Key words: *Trichogrammatoidea bactrae* Nagaraja; temperature; life table; sex ratio

文章编号:1000-0933(2005)01-0073-05 **中图分类号**:Q142,Q145,Q968.1 **文献标识码**:A

卷蛾分索赤眼蜂 *Trichogrammatoidea bactrae* Nagaraja 属赤眼蜂科 Trichogrammatidae,分索赤眼蜂属 *Trichogrammatoidea*,是鳞翅目害虫重要的卵期寄生蜂。主要分布于热带和亚热带地区,印度、马来西亚、泰国、巴基斯坦、澳大利亚、非洲等地,我国的台湾和福建都有该蜂的记载,寄生为害甘蔗、水稻、棉花、蔬菜及玉米的鳞翅目害虫卵[1~3]。近年来,在一些实验室进行的寄生小菜蛾卵的寄生蜂种类的筛选实验中,卷蛾分索赤眼蜂表现出对小菜蛾卵较强的选择性,认为该蜂对小菜蛾有较大的控制潜能,是防治小菜蛾的适宜蜂种[4~7]。在泰国对小菜蛾卵的自然寄生率高达45.2%[8];在国内,黄寿山等在深圳龙岗生态示范农场首次发现了其自然寄生小菜蛾卵的现象,且寄生率逐年增加,显示出良好的应用前景[9]。

虽然卷蛾分索赤眼蜂在实验室筛选中被认为是寄生小菜蛾的最适宜蜂种之一,但有关其生物学、生态学特性却未有系统、深入的研究报道。探讨主要环境因子——温度对卷蛾分索赤眼蜂发育、存活及繁殖等方面的影响,对于阐明其田间种群数量变动的规律,提高其控害潜能有着积极的意义。同时,赤眼蜂对温度的适应性,尤其是极端温度的适应性,是天敌引进的一个重要参考指标[10]。

1 材料

1.1 供试蜂种

卷蛾分索赤眼蜂(*Trichogrammatoidea bactrae* Nagaraja),采自深圳龙岗示范生态农场菜芯地小菜蛾卵,并在室内用米蛾卵繁育约10代以上。

1.2 供试寄主

米蛾 *Corcyra cephalonica* (Stainton)卵,在室内用面粉饲养。所用寄主在繁蜂前均用30W的紫外灯照射30min,杀死其胚胎。

1.3 控温设备

人工气候箱 PXY-300Q-A型,广东韶关科力实验仪器有限公司生产。

1.4 试验方法

1.4.1 温度对赤眼蜂生长发育和存活的影响 试验设17、20、23、26、29、32℃和35℃7个梯度恒温,相对湿度设定为75%,光照:14:10(L:D)。在卷蛾分索赤眼蜂羽化高峰期接上大小为4cm×5cm米蛾卵卡(室内赤眼蜂的培育温度为26℃),30min后将卵卡取出,将其均分1cm×5cm大小的卵卡3张。观察各梯度恒定温度下赤眼蜂的发育进程,逐日统计各蜂种的羽化出蜂数,直至出蜂完毕。发育速率(V)与温度(T)之间的关系采用王-兰-丁模型进行拟合[11]:

$$V_{(T)} = K \times [1 - e^{[-(T-TL)/\delta]}] \times [1 - e^{[-(TH-T)/\delta]}]/[1 + e^{[-\gamma(T-T0)]}]$$

式中,$V_{(T)}$ 为温度 T 下的发育速率;K 为常温下潜在的饱和发育速率;γ 为发育速率随温度变化的指数增长率;T_L、T_H 为最低、最高临界温度;T_0 为最适发育温度;δ 为边界层的宽度,其大小刻划了昆虫对极端温度的忍耐程度。

1.4.2 温度对赤眼蜂繁殖力的影响 参照黄寿山等所介绍的方法[12],组建卷蛾分索赤眼蜂在不同梯度恒温条件下的实验种群生命表。取接种30min以内的寄生卵(500粒以上)作为供试材料。记录接种时间作为 x(实验种群生命表组建中雌性个体的

年龄)计算的起点,x 以 24h 为单位。在赤眼蜂羽化当日,供给浓度为 25%的蜂蜜水溶液,让其充分交配 12h 后单蜂引入直径 1.1cm、长 5.5cm 的指形管中,管壁同样点涂有浓度为 25%蜂蜜水溶液,30～50 头雌蜂。对每头雌蜂分别编号,并接以过量(200 粒/d)米蛾卵。24h 更换 1 次卵卡,将更换下的卵卡放入相同试验条件下培养。逐日观察并记录每头雌蜂的存活情况、逐日寄生卵数、逐日产出雌性子代数(逐日产雌数是在子代蜂羽后的实际统计结果)作为繁殖力估计。生命表参数的计算参照 Birch、徐汝梅的方法[13,14]。

1.5　数据处理

试验数据用 SAS6.12(SAS Institute)程序进行统计分析[15]。

2　结果与分析

2.1　温度对卷蛾分索赤眼蜂幼期存活率的影响

图 1 显示了温度对卷蛾分索赤眼蜂幼期(卵到成蜂羽化阶段)生长发育的影响。17℃时,卷蛾分索赤眼蜂的幼期存活率均在 80%以上,随着温度的升高赤眼蜂的存活率也平缓上升,到 20℃时开始进入一个较明显的生长发育适期,至 29℃赤眼蜂的幼期存活率维持在 90%以上。在 29℃后,该蜂的幼期存活率逐渐下降,32℃时存活率急剧下降,至 35℃时其存活率仅 12.98%。

2.2　卷蛾分索赤眼蜂发育历期与温度的关系

在介于 17～35℃之间的 7 个梯度恒温范围内,温度越低,卷蛾分索赤眼蜂的发育历期越长(图 2)。在 17℃时,其世代历期为 20.77d,随着温度的升高其世代历期急剧缩短,到 29℃时,卷蛾分索赤眼蜂的发育历期仅为 7.22d,各温度梯度间的差异显著。在 29～35℃之间,该蜂的发育历期变化较为平缓。

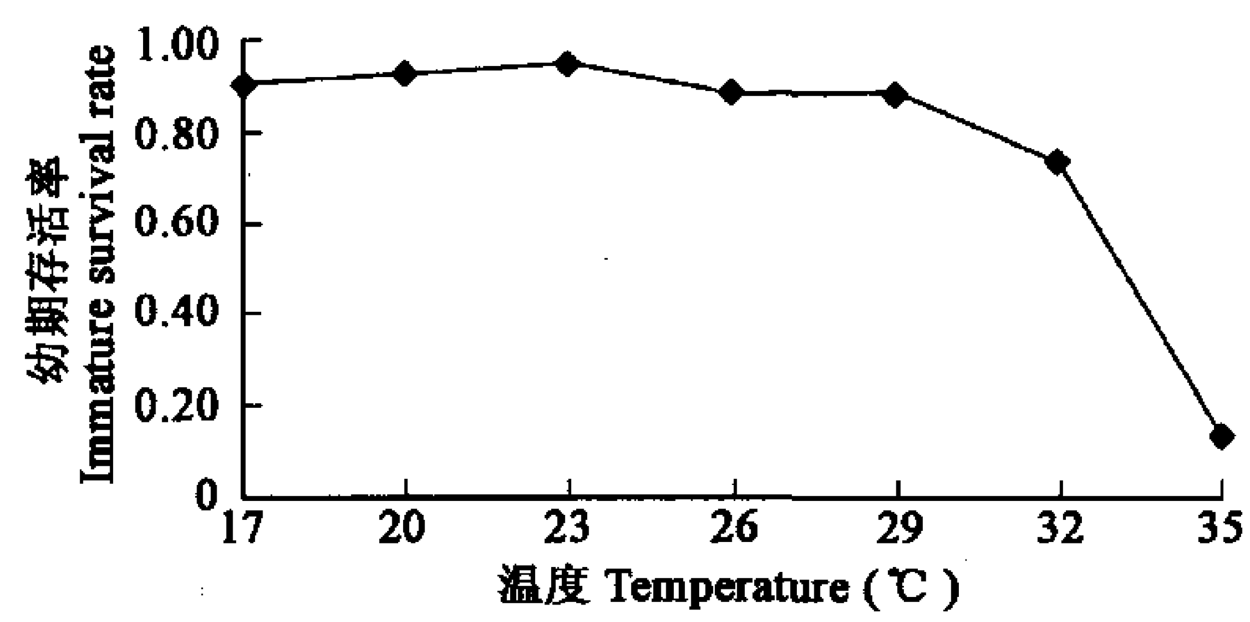

图 1　温度对卷蛾分索赤眼蜂幼期存活率的影响

Fig. 1　Effect of temperature on the immature survival rate of *Trichogrammatoidea bactrae*

2.3　卷蛾分索赤眼蜂发育速率与温度的关系

将发育历期 (N) 换算成发育速率(V),$V = 1/N$,计算出卷蛾分索赤眼蜂在不同温度下的发育速率,采用麦夸特(Marquardt)阻尼最小二乘法迭代出卷蛾分索赤眼蜂发育速率与温度关系的王-兰-丁模型:

$$V = 0.1941 \times [1 - e^{[-(T-11.92)/2.80]}] \times [1 - e^{[-(38.95-T)/2.80]}]/[1 + e^{[-0.1678(T-23.07)]}] \quad R^2 = 0.97^{**}$$

卷蛾分索赤眼蜂的最低和最高临界发育温度分别为 11.92℃和 38.95℃,最适发育温度为 23.07℃。发育速率与温度间的关系见图 3。

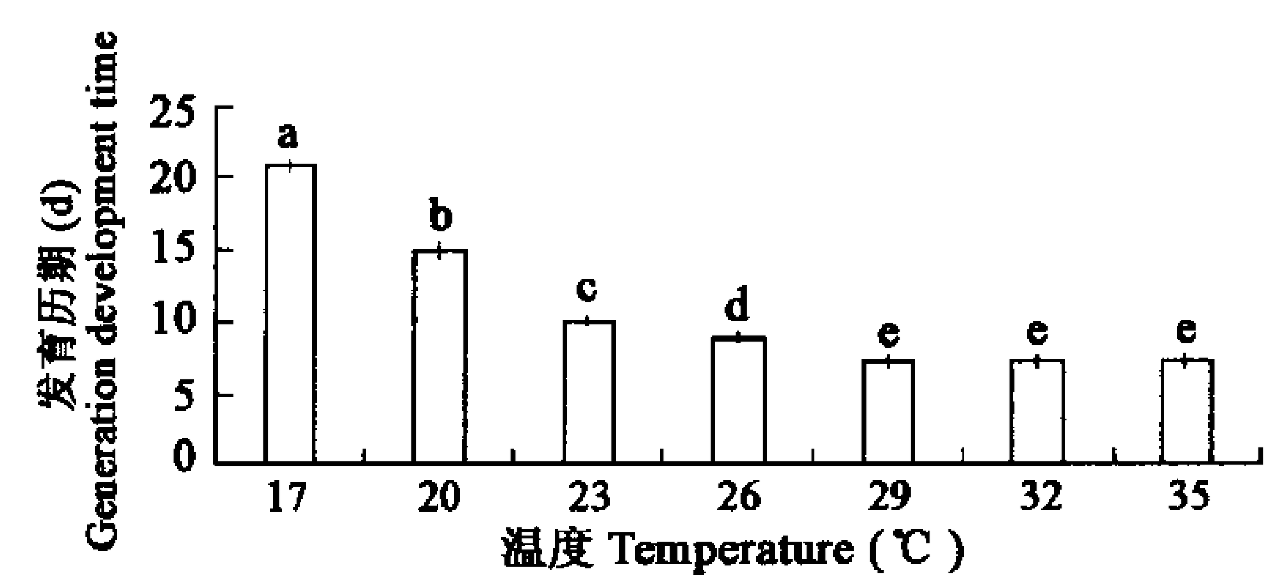

图 2　温度对卷蛾分索赤眼蜂世代发育历期影响

Fig. 2　Effect of temperature on the generation development time of *Trichogrammatoidea bactrae*

图中直方柱上方字母为 DMRT 法比较结果,不同字母表示在 0.05 水平上差异显著 Bars with different letters indicate significant difference at 5% level (DMRT)

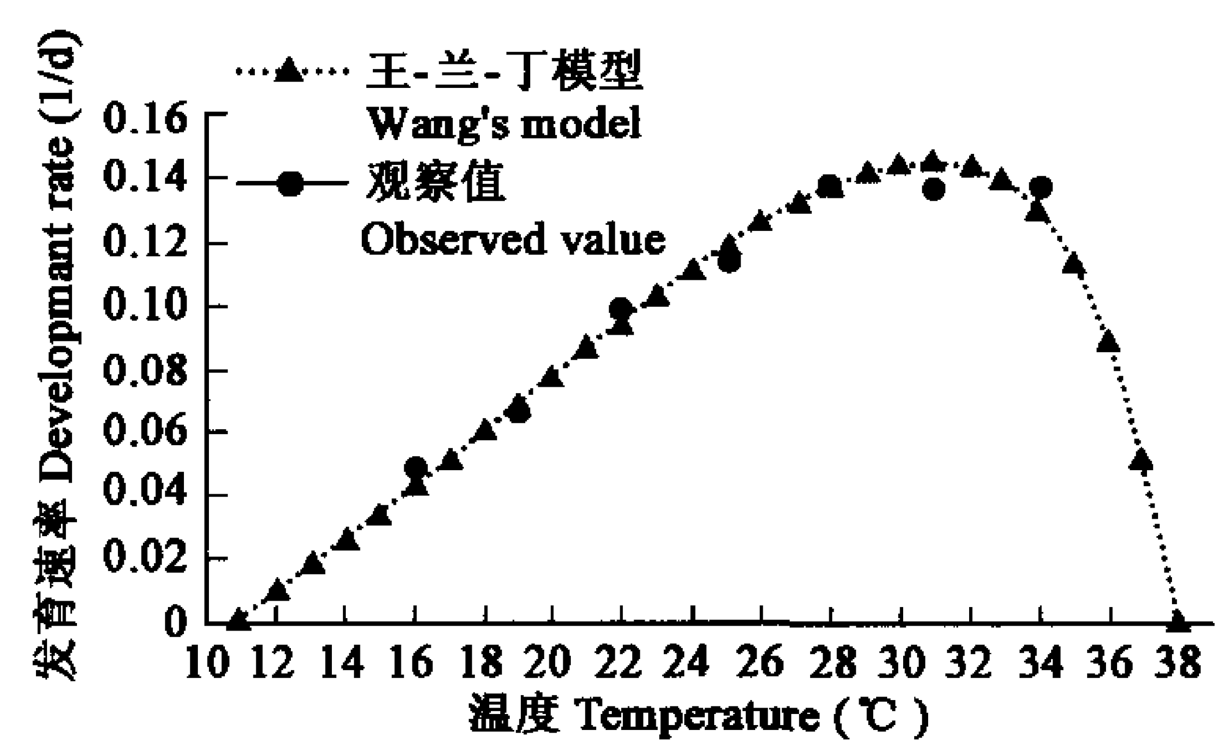

图 3　卷蛾分索赤眼蜂发育速率与温度的关系

Fig. 3　Relationship between the temperature and development rate of *Trichogrammatoidea bactrae*

2.4　温度对卷蛾分索赤眼蜂子代性比的影响

温度对卷蛾分索赤眼蜂的性比有明显的影响,在试验梯度温度 17～35℃范围内,卷蛾分索赤眼蜂的仔代性比随温度的升高而逐渐下降,见表 1。在 17℃,卷蛾分索赤眼蜂获得了试验温度范围内最高的仔代雌雄性比,为 6.73,随后卷蛾分索赤眼蜂的仔代性比逐步下降。17℃至 20℃,仔代雌雄性比从 6.73 下降至 3.48,差异极显著。从 23℃开始逐渐进入一个性比相对平稳的时期,至 29℃结束。从 29℃开始,卷蛾分索赤眼蜂的仔代雌雄性比进一步下降,至 32℃下降为 1.75。

卷蛾分索赤眼蜂在试验温度范围的仔代性比变化呈负指数增长,经拟合,符合下列指数方程:$S = e^{(3.51-0.17T)}$,(相关指数

$R^2=0.97^{**}$)，式中 S 代表卷蛾分索赤眼蜂的仔代雌雄性比，T 为试验温度。

表 1 温度对卷蛾分索赤眼蜂子代性比的影响(雌：雄)

Table 1 Effect of temperature on the progeny female to male sex ratio of *Trichogrammatoidea bactrae*

温度 Temperature(℃)						
17	20	23	26	29	32	35
6.73±0.64A	3.48±0.36B	2.88±0.27BC	2.45±0.32BC	2.41±0.31BC	1.75±0.38C	—

表中数字后字母为 DMRT 法比较的结果，字母相同表示在 0.01 水平上差异不显著，字母不同表示差异显著 Means followed by the same letter are not significantly different at 1% level(DMRT)

各温度处理下赤眼蜂仔代性比曲线见图 4。

2.5 卷蛾分索赤眼蜂实验种群生命表参数对梯度恒温的响应

从温度对成蜂寿命的影响来看，卷蛾分索赤眼蜂有一个较明显的适温期。其适温区介于 20～29℃之间。卷蛾分索赤眼蜂对极端温度的反应比较敏感，17℃时雌成蜂寿命为 4.86d，32℃为 2.34d，而在 35℃时，羽化当天所有成蜂就死亡，存活不到 1d，表现出对极端温度的不适应性。

从寄生卵量来看，在 17℃时，卷蛾分索赤眼蜂的寄生卵量较低，为 31.93 粒/雌，随着温度的升高，卷蛾分索赤眼蜂寄生卵量逐渐提高，在 23℃时达到其寄生卵量的高峰期，103.91 粒/雌。与此同时，卷蛾分索赤眼蜂的内禀增长率 r_m 也随温度升高而加快，到 29℃达到最大值，为 0.489。从 32℃开始，其内禀增长率急剧下降，至 35℃时，其种群不再增殖(表 2)。

表 2 温度对卷蛾分索赤眼蜂种群参数的影响

Table 2 Effect of temperature on the population parameters of *Trichogrammatoidea bactrae*

种群参数 Population parameters	温度 Temperature(℃)						
	17	20	23	26	29	32	35
寄生卵量 Fecundity(eggs)	31.93±1.80D	65.19±4.88C	103.91±4.88A	99.71±5.32A	83.00±5.33B	6.10±1.82E	0
R_0	23.56	42.39	64.23	52.71	42.32	2.27	0
r_m	0.1559	0.2395	0.3519	0.4346	0.4890	0.1111	—
T	20.27	15.65	11.83	9.12	7.66	7.38	—
λ	1.17	1.27	1.42	1.54	1.63	1.11	—
雌蜂寿命 Female longevity(d)	4.86±0.28D	9.31±0.45B	10.87±0.52A	9.76±0.41B	7.67±0.42C	2.34±0.09E	1±0.00 F

R_0 净生殖力 net reproduction rate；r_m 内禀增长率 intrinsic rate of natural increase；T 世代发育历期 generation development time；λ 周限增长率 finite rate of increase；表中同行数字后字母为 DMRT 法比较的结果，字母相同表示在 0.01 水平上差异不显著，字母不同表示差异显著 Means followed by the same letter within columuns are not significantly different at 1% level (DMRT)

卷蛾分索赤眼蜂的净生殖力 R_0 在试验温度范围内表现两端低，中间高的抛物线特征趋势(图 5)，经拟合，其抛物线方程为：

$$R_0 = -0.55T^2 + 26.33T - 263.4 \quad (\text{相关指数 } R^2 = 0.98^*)$$

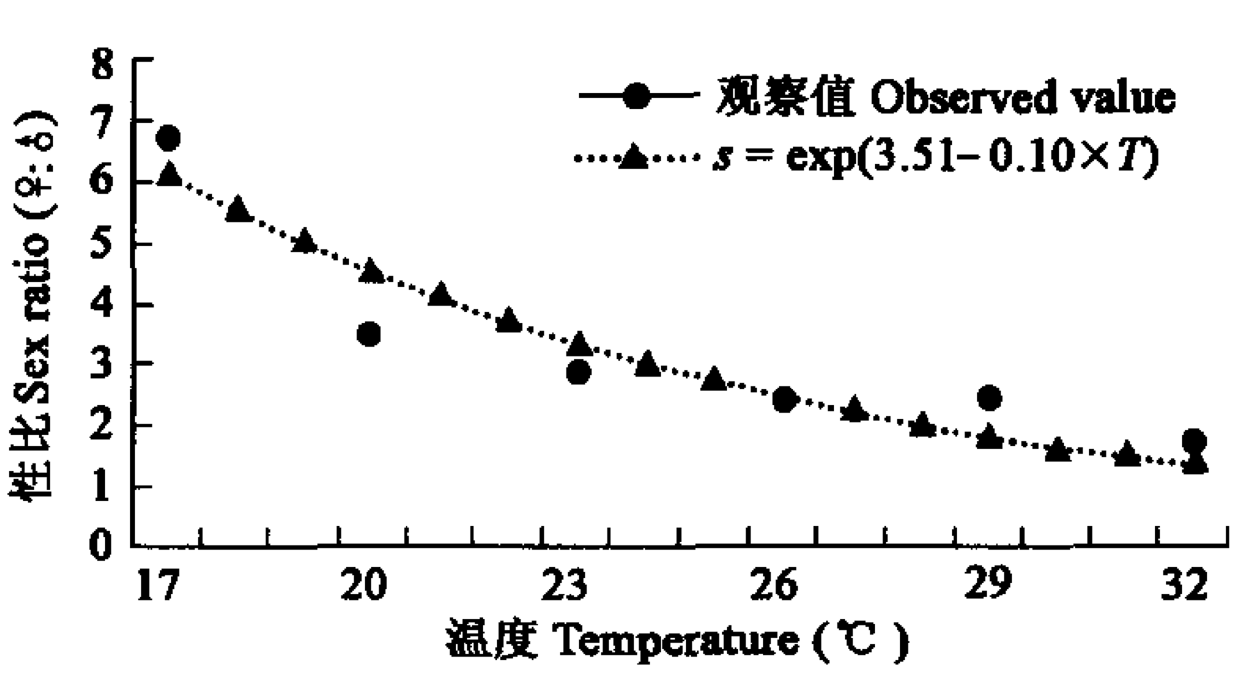

图 4 温度对卷蛾分索赤眼蜂子代性比的影响

Fig. 4 Effect of temperature on the progeny sex ratio of *Trichogrammatoidea bactrae*

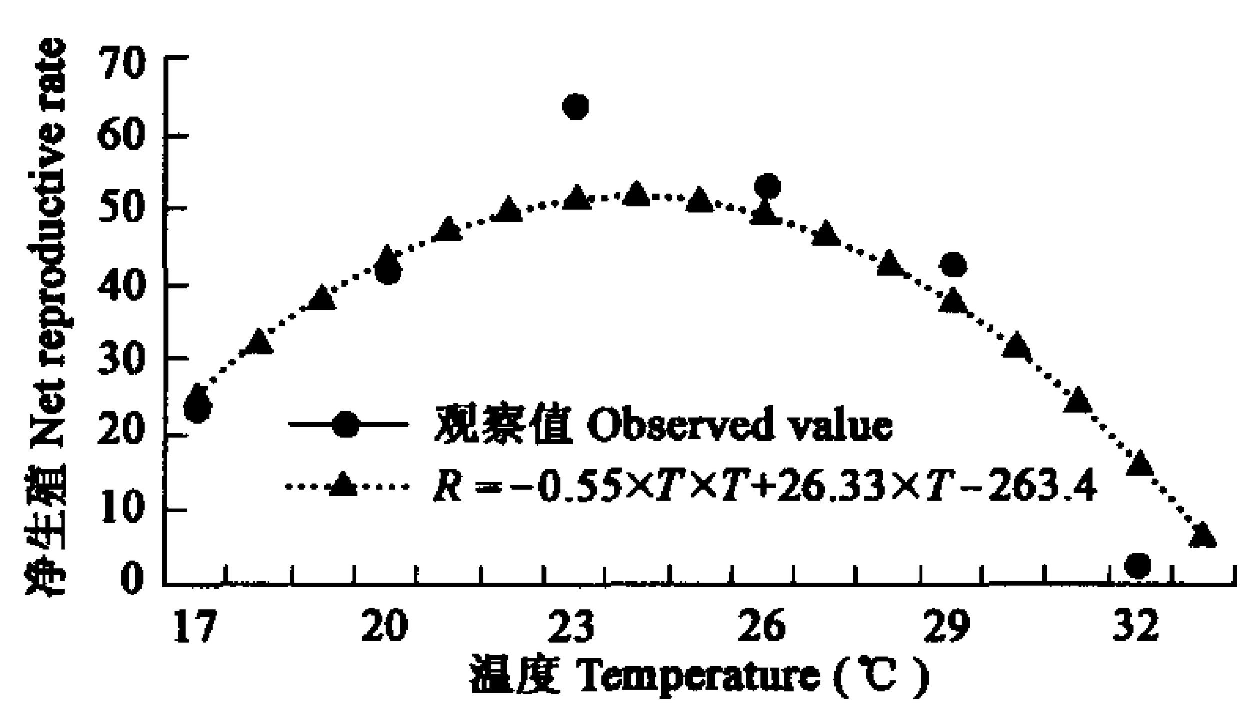

图 5 温度对卷蛾分索赤眼蜂净生殖力的影响

Fig. 5 Effect of temperature on the net reproductive rate of *Trichogrammatoidea bactrae*

3 结论与讨论

3.1 从温度对卷蛾分索赤眼蜂的幼期存活率、平均寄生卵量、净生殖力、内禀增长率、成蜂寿命等生物学指标的影响来看，在 17℃及 32～35℃情况下，其生长发育及生殖力都受到明显的抑制，表现出对极端温度的不适应性。温度过高或过低都对其生活力有明显的抑制作用。其临界发育温度为 11.95℃和 38.95℃，适温范围较窄，在 35℃时，其种群就不能再增殖，这与黄寿山等所

报道的其田间的季节性消长动态是相一致的[9]。但国外有报道称,卷蛾分索赤眼蜂对高温有较强的忍耐性,在 40℃还能进行繁殖活动[16],这是否与不同地理种群有关,有待进一步探讨。

3.2 温度对卷蛾分索赤眼蜂的子代性比有着显著的影响。在试验温度范围内,卷蛾分索赤眼蜂的子代雌雄性比随着温度的升高而不断下降,从 17℃时的 6.73 降至 32℃时的 1.75。目前,温度对赤眼蜂性比影响机理的并不清晰,是因为高温影响了赤眼蜂卵巢的发育,还是高温影响了精子的正常产生,或是影响赤眼蜂的活动能力导致交配失败,这些问题都有待深入研究。

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