

柞蚕灰卵繁育的螟黄赤眼蜂寄生 米蛾卵生物学特性的研究*

孙健智^{1**} 杨添元¹ 赵哲语¹ 潘业兴¹ 范文忠¹ 代力强¹
关 雷¹ 赵丽娜^{1***} 臧连生^{2***}

(1. 吉林农业科技学院农学院, 吉林 132101; 2. 贵州大学绿色农药与农业生物工程教育部重点实验室, 贵阳 550025)

摘 要 【目的】明确柞蚕 *Antheraea pernyi* 灰卵（工厂化繁育赤眼蜂过程中的一种感病寄主卵）繁育的螟黄赤眼蜂 *Trichogramma chilonis* 对米蛾 *Corcyra cephalonica* 卵的寄生能力与发育适合度，为寄主卵质量控制提供依据。【方法】以柞蚕灰卵繁育的子代赤眼蜂为处理组，健康卵繁育的子代赤眼蜂为对照组，比较两组赤眼蜂对冷藏 0、1、2 和 3 d 米蛾卵的寄生量、羽化率、发育历期和后代雌性比。【结果】处理组赤眼蜂在冷藏 0-3 d 米蛾卵的寄生量显著低于对照组的寄生量 ($P < 0.05$)。两组赤眼蜂在冷藏 0 d 米蛾卵的羽化率、发育历期均无显著差异 ($P > 0.05$)；处理组在冷藏 1、2 和 3 d 米蛾卵的羽化率均显著低于对照组的羽化率 ($P < 0.05$)，而处理组在冷藏 1、2 和 3 d 米蛾卵的发育历期均显著长于对照组的发育历期 ($P < 0.05$)。两组赤眼蜂在冷藏 0 和 1 d 米蛾卵的雌性比无显著差异 ($P > 0.05$)；处理组在冷藏 2 和 3 d 米蛾卵的雌性比均显著高于对照组的雌性比 ($P < 0.05$)。【结论】柞蚕灰卵作为寄主卵会对螟黄赤眼蜂子代蜂的寄生能力与发育适合度产生一定程度的不良影响。

关键词 发育适合度；寄主质量；寄生能力；米蛾卵

Study on the biological characteristics of *Trichogramma chilonis* parasitizing *Corcyra cephalonica* eggs reared by the gray eggs of *Antheraea pernyi*

SUN Jian-Zhi^{1**} YANG Tian-Yuan¹ ZHAO Zhe-Yu¹ PAN Ye-Xing¹ FAN Wen-Zhong¹
DAI Li-Qiang¹ GUAN Lei¹ ZHAO Li-Na^{1***} ZANG Lian-Sheng^{2***}

(1. College of Agriculture, Jilin Agricultural Science and Technology College, Jilin 132101, China;

2. Key Laboratory of Green Pesticide and Agricultural Bioengineering, Guizhou University, Guiyang 550025, China)

Abstract 【Aim】To clarify the parasitic ability and developmental fitness of *Trichogramma chilonis* from the gray eggs of *Antheraea pernyi* on *Corcyra cephalonica* eggs, a host egg susceptible to bacteria during massive production of *T. chilonis*. This study aims to provide a basis for host egg quality control. 【Methods】*Trichogramma* offspring reared by the gray eggs served as the treatment group, while *Trichogramma* offspring reared by the healthy eggs served as the control group. The parasitism rate, emergence rate, developmental duration and female proportion of *Trichogramma* offspring reared by the two groups were compared on refrigerated 0-3-day-old eggs of the rice moth *C. cephalonica*. 【Results】The offspring reared from the control group (healthy eggs) significantly parasitized more eggs on refrigerated 0-3-day-old eggs of *C. cephalonica* than that from the treatment group (gray eggs) ($P < 0.05$). There were no significant difference in emergence rate and developmental duration on refrigerated 0-day-old eggs of *C. cephalonica* between the offspring reared from the two groups ($P > 0.05$). The emergence rate of offspring reared from the treatment group on refrigerated 1-3-day-old eggs of *C.*

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**第一作者 First author, E-mail: 1123036787@qq.com

***共同通讯作者 Co-corresponding authors, E-mail: 372219237@qq.com; lsz0415@163.com

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cephalonica was significantly lower than that from the control group ($P < 0.05$). However, the developmental duration of offspring reared from the treatment group on refrigerated 1-3-day-old eggs of *C. cephalonica* was significantly higher than that from the control group ($P < 0.05$). There was no significant difference in female proportion on refrigerated 0- or 1-day-old eggs of *C. cephalonica* between the offspring reared from the two groups ($P > 0.05$). The female proportion of offspring reared from the treatment group on refrigerated 2- or 3-day-old eggs of *C. cephalonica* was significantly higher than that from the control group ($P < 0.05$). **[Conclusion]** The results indicated that the gray eggs of *A. pernyi* caused by bacteria could some adversely affect the parasitic ability and developmental fitness of *T. chilonis*.

Key words developmental fitness; host quality; parasitic ability; *Corcyra cephalonica* eggs

赤眼蜂是世界范围内作为生物防治鳞翅目害虫常见的卵寄生蜂 (Smith, 1996; Du *et al.*, 2018)。利用柞蚕 *Antheraea pernyi* 卵进行赤眼蜂的工厂化生产和释放已得到大规模推广, 并取得了较高的生态效益和经济效益 (张荆等, 1990)。近年来, 在工厂化生产赤眼蜂过程中, 不断有大量的柞蚕灰卵 (病原菌为粘质沙雷菌 *Serratia marcescens*) 出现 (Zhao *et al.*, 2020), 严重影响了赤眼蜂的质量及产量 (阮长春等, 2000)。因此, 明确柞蚕灰卵对子代赤眼蜂寄生能力与发育适合度的影响至关重要。

很多学者以寄生蜂与寄主的组合为研究对象, 探讨了昆虫病原微生物对寄生蜂产生的影响。在一般情况下, 昆虫病原微生物对寄生蜂产生的影响均是不利的 (王以一等, 2014)。也有较多的试验结果表明, 病原菌会直接影响在感病寄主体内发育的赤眼蜂, 导致赤眼蜂发育减缓甚至死亡等 (李元喜等, 2002; 蒋杰贤等, 2005; 李增梅等, 2005)。光腹悬茧蜂 *Meteorus laeviventris* 被苏云金芽孢杆菌 *Bacillus thuringiensis* 感染后, 子代蜂结茧率下降、发育历期延长 (Hafez *et al.*, 1997)。病原微生物还会导致寄生蜂的羽化率下降 (Mason *et al.*, 2002; Schneider *et al.*, 2003), 也会使赤眼蜂成虫体积减小, 进而使赤眼蜂寻找、产卵等行为发生改变 (Mohan *et al.*, 2008)。某些情况下, 病原微生物也会对寄生蜂的寄生能力造成影响, 最终导致其控害潜能有所下降 (古德就等, 1991); 已有研究明确指出寄生蜂和真菌、寄生蜂和病毒间的相互作用关系, 例如绿僵菌 *Metarhizium anisopliae* (彭辉银等, 1998)、核型多角体病毒 (Irabagon and Brooks, 1974; Beegle and

Oatman, 1975) 和质型多角体病毒等 (边强等, 2010), 而对病原细菌的研究却较少, 大部分是有关苏云金芽孢杆菌的 (孙光芝等, 2005; 陈日璽等, 2007)。

感染病原菌的寄主被赤眼蜂寄生以后, 一些毒素会随着寄主的病原菌产生, 从而对在寄主中发育的子代蜂产生毒害作用, 影响子代蜂的生长发育和存活 (Kaya and Tanada, 1973), 一些子代蜂由于在寄主体内未能完成发育过程而死亡; 还有一些虽然能够正常羽化出蜂, 但寄生蜂的寄生能力、发育历期、后代雌性比等可能会受到影响 (马月, 2019)。虽然目前国内外关于感病寄主与寄生蜂关系的研究较多, 但关于柞蚕灰卵对子代蜂寄生生物学特性的影响尚不明确。本研究以柞蚕灰卵与健康卵繁育的螟黄赤眼蜂 *Trichogramma chilonis* 为对象, 通过比较其对不同冷藏时间米蛾 *Corcyra cephalonica* 卵的寄生能力与发育适合度, 揭示灰卵的负面影响, 为后续研究柞蚕灰卵对寄生蜂种群调控的分子机制提供基础数据。

1 材料与方法

1.1 供试材料

健康的柞蚕卵: 从吉林省农业科学院赤眼蜂工厂购入试验用的柞蚕茧, 在柞蚕饲养室进行饲养, 饲养条件为温度 (25 ± 1) °C, 相对湿度 $60\% \pm 5\%$, 光周期 14 L : 10 D, 将初羽化且未交配的柞蚕雌蛾置于 4 °C 冰箱冷藏 2-3 d, 待卵成熟后取出, 剖腹取卵粒, 然后用自来水洗净, 晾干, 选取大小均一且健康的卵作为试验材料。

柞蚕灰卵: 将健康柞蚕卵浸泡于粘质沙雷氏

菌悬液 (10^8 cfu/mL) 中, 5 h 后取出晾干, 24 h 后即可得到灰卵 (南楠, 2014; 马月, 2019)。

螟黄赤眼蜂 (贵州本地玉米螟 *Ostrinia furnacalis* 卵块中获取): 由吉林农业大学生物防治研究所提供, 依据形态学及分子生物学进行鉴定 (郭震等, 2012), 并利用米蛾卵建立试验种群, 环境条件为温度 (25 ± 1) °C, 相对湿度 $70\% \pm 5\%$, 光周期 14 L : 10 D, 在室内连续繁殖 10 代以上。试验采用刻度试管, 其规格为 2 cm×10 cm。向试管中加入 5 粒柞蚕灰卵, 然后引入 10 头羽化 8 h 且充分交配的雌蜂, 并置于恒温培养箱 (MLR-351H, 日本三洋电气有限公司) 中, 设定参数为温度 (25 ± 1) °C, 相对湿度 $70\% \pm 5\%$, 光周期 14 L : 10 D, 24 h 后移除雌蜂, 然后将每粒柞蚕卵进行单管分装, 以健康的柞蚕卵作为对照。待子代蜂羽化出蜂后, 分别选择从柞蚕灰卵和健康卵中繁育的子代赤眼蜂雌蜂作为供试寄生蜂。

米蛾卵: 米蛾是在吉林农业大学生物防治研究所人工饲养, 待其羽化成蛾, 收取当日所产的新鲜米蛾卵, 然后在紫外灯下杀胚 30 min, 制成规格为 0.5 cm×1.0 cm 的米蛾卵卡, 每张卵卡约为 200 粒米蛾卵, 将其放到 4 °C 冰箱冷藏 0、1、2 和 3 d 后, 用于后续试验。

1.2 实验方法

以柞蚕灰卵繁育的羽化后 8 h 内并充分交配的赤眼蜂为测试蜂种, 在 2 cm×10 cm 的各试管中分别放入约 200 粒的冷藏 0、1、2 和 3 d 的米蛾卵卡, 然后将单头雌蜂分别引入到试管中, 实验条件为温度 (25 ± 1) °C, 相对湿度 $70\% \pm 5\%$, 光周期 14 L : 10 D, 每 24 h 更换新鲜卵卡, 直至雌蜂死亡。待子代赤眼蜂羽化结束后, 调查寄生米蛾卵数、羽化率、发育历期及后代雌性比, 以健康柞蚕卵繁育的赤眼蜂作为对照。共设计 8 组处理, 每个处理重复 30 次。

1.3 数据分析

采用独立样本 *t* 检验 (Student's *t* test) 分析柞蚕灰卵和健康卵繁育的子代赤眼蜂在相同冷藏时间米蛾卵上的寄生量、羽化率、发育历期及

后代雌性比的差异显著性 ($P < 0.05$)。采用 Tukey's HSD 检验分析相同处理寄主卵繁育的子代赤眼蜂在不同冷藏时间米蛾卵上的寄生量、羽化率、发育历期及后代雌性比的差异显著性 ($P < 0.05$)。所有数据通过 DPS (v14.1) 软件进行统计分析, 并利用 Excel 2019 进行整理和制图。

2 结果与分析

2.1 柞蚕灰卵和健康卵繁育的螟黄赤眼蜂对米蛾卵寄生能力的比较

柞蚕灰卵和健康卵繁育的螟黄赤眼蜂对冷藏不同时间米蛾卵的寄生能力比较结果见图 1。

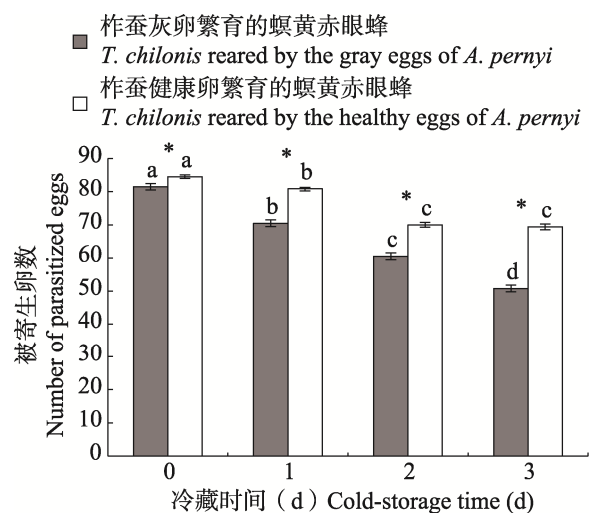


图 1 柞蚕灰卵和健康卵繁育的螟黄赤眼蜂对米蛾卵的寄生量

Fig. 1 Parasitism rate of *Trichogramma chilonis* reared by the gray and healthy eggs of *Antheraea pernyi* on *Corcyra cephalonica* eggs

图中数据为平均值±标准误。同色柱上不同小写字母表示赤眼蜂对不同冷藏时间米蛾卵的寄生量差异显著 ($P < 0.05$, Tukey's HSD 检验); 成对柱形图上*表示两种寄主卵繁育的赤眼蜂对相同冷藏时间米蛾卵的寄生量差异显著 ($P < 0.05$, Student's *t* 检验)。

Data in the figure are mean±SE. Different lowercase letters above the same color bars indicate significant difference in the parasitism rate of *Trichogramma* wasps on *C. cephalonica* eggs with different cold-storage time ($P < 0.05$, Tukey's HSD test). The paired bars with * indicate significant difference in the parasitism rate of *Trichogramma* wasps reared by the two different host eggs on *C. cephalonica* eggs with the same cold-storage time ($P < 0.05$, Student's *t*-test).

处理组(柞蚕灰卵繁育的螟黄赤眼蜂)在不同冷藏时间米蛾卵的寄生量: 冷藏 0 d > 冷藏 1 d > 冷藏 2 d > 冷藏 3 d ($F_{3,36} = 388.579$, $P < 0.001$); 对照组(柞蚕健康卵繁育的螟黄赤眼蜂)在冷藏 0 d 米蛾卵的寄生量显著高于在冷藏 1、2 和 3 d 米蛾卵的寄生量 ($F_{3,36} = 585.533$, $P < 0.001$), 而在冷藏 2 和 3 d 米蛾卵的寄生量无显著差异 ($t = 0.542$, $df = 18$, $P = 0.595$)。

当提供冷藏 0-3 d 的米蛾卵时, 处理组的寄生量均显著低于对照组的寄生量(冷藏 0 d: $t = 2.007$, $df = 18$, $P < 0.001$; 冷藏 1 d: $t = 13.502$, $df = 18$, $P < 0.001$; 冷藏 2 d: $t = 9.175$, $df = 18$, $P < 0.001$; 冷藏 3 d: $t = 15.720$, $df = 18$, $P < 0.001$)。

2.2 柞蚕灰卵和健康卵繁育的螟黄赤眼蜂在米蛾卵上的发育适合度

由柞蚕灰卵和健康卵繁育的螟黄赤眼蜂寄生不同冷藏时间的米蛾卵后, 螟黄赤眼蜂子代蜂的羽化率、发育历期和后代雌性比的比较结果见表 1。当提供冷藏 0 d 的米蛾卵时, 两组(柞蚕灰卵和健康卵繁育的螟黄赤眼蜂)在米蛾卵的羽化率无显著差异 ($t = 0.074$, $df = 18$, $P = 0.942$); 当提供冷藏 1、2 和 3 d 的米蛾卵时, 处理组(柞蚕灰卵繁育的螟黄赤眼蜂)在米蛾卵的羽化率均显著低于对照组(柞蚕健康卵繁育的螟黄赤眼蜂)在米蛾卵的羽化率(冷藏 1 d: $t = 3.718$, $df = 18$, $P = 0.002$; 冷藏 2 d: $t = 8.686$, $df = 18$, $P < 0.001$; 冷藏 3 d: $t = 24.665$, $df = 18$, $P < 0.001$)。处理组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在冷藏 0 和 1 d 的米蛾卵上的羽化率显著高于在冷藏 2 和 3 d 的米蛾卵上的羽化率 ($F_{3,36} = 580.166$, $P < 0.001$); 对照组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在冷藏 1 d 的米蛾卵上的羽化率显著高于在冷藏 0、2、3 d 的米蛾卵上的羽化率 ($F_{3,36} = 6.327$, $P < 0.001$)。

当提供冷藏 0 d 的米蛾卵时, 两组(柞蚕灰卵和健康卵繁育的螟黄赤眼蜂)在米蛾卵的发育历期无显著差异 ($t = 1.333$, $df = 18$, $P = 0.199$); 当提供冷藏 1、2、3 d 的米蛾卵时, 处理组在米

蛾卵的发育历期均显著长于对照组在米蛾卵的发育历期(冷藏 1 d: $t = 2.948$, $df = 18$, $P = 0.009$; 冷藏 2 d: $t = 4.270$, $df = 18$, $P < 0.001$; 冷藏 3 d: $t = 2.199$, $df = 18$, $P = 0.041$)。处理组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在米蛾卵的发育历期无显著差异 ($F_{3,36} = 1.840$, $P = 0.157$); 对照组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在冷藏 3 d 的米蛾卵上的发育历期显著高于在冷藏 0、1 和 2 d 的米蛾卵上的发育历期 ($F_{3,36} = 5.907$, $P = 0.002$)。

当提供冷藏 0 和 1 d 的米蛾卵时, 两组(柞蚕灰卵和健康卵繁育的螟黄赤眼蜂)在米蛾卵的雌性比无显著差异(冷藏 0 d: $t = 0.327$, $df = 18$, $P = 0.747$; 冷藏 1 d: $t = 0.631$, $df = 18$, $P = 0.536$); 当提供冷藏 2 和 3 d 的米蛾卵时, 处理组在米蛾卵的雌性比均显著高于对照组在米蛾卵的雌性比(冷藏 2 d: $t = 3.873$, $df = 18$, $P < 0.001$; 冷藏 3 d: $t = 5.685$, $df = 18$, $P < 0.001$)。处理组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在冷藏 2 和 3 d 的米蛾卵的雌性比显著高于在冷藏 0 和 1 d 的米蛾卵的雌性比 ($F_{3,36} = 18.970$, $P < 0.001$); 对照组寄生冷藏 0-3 d 的米蛾卵后, 子代蜂在米蛾卵上的雌性比无显著差异 ($F_{3,36} = 0.178$, $P = 0.911$)。

3 结论与讨论

病原菌可能导致寄生蜂子代蜂发育异常的原因包括毒素积累: 粘质沙雷菌产生的代谢物直接抑制幼虫发育 (Kaya and Tanada, 1973); 营养剥夺: 病原菌竞争寄主卵内资源 (Walker *et al.*, 2007); 免疫激活: 寄主卵免疫反应间接损害寄生蜂 (Salama and Zaki, 1983)。寄生蜂感染病原微生物后羽化率降低 (Mason *et al.*, 2002; Schneider *et al.*, 2003), 成虫体态变小, 其搜寻和产卵等行为会受到影响 (Mohan *et al.*, 2008)。在本研究中, 柞蚕灰卵繁育的子代赤眼蜂在寄生冷藏 1、2 和 3 d 的米蛾卵后, 其羽化率均低于健康卵繁育的子代赤眼蜂羽化率。不同致病菌感染寄主后被赤眼蜂寄生, 子代赤眼蜂的羽化率降低, 并且雌蜂的寄生能力也随之降低

表 1 柞蚕灰卵和健康卵繁育的螟黄赤眼蜂在米蛾卵上的发育适合度
Table 1 Developmental fitness of *Trichogramma chilonis* reared by the gray and healthy eggs of *Antheraea pernyi* on *Coryca cephalonica* eggs

生物学参数 Biological parameter	蜂种 Species	冷藏时间 (d) Cold-storage time (d)				显著水平 Significant level
		0	1	2	3	
羽化率 (%) Emergence rate (%)	柞蚕灰卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the gray eggs of <i>A. pernyi</i>	89.55±0.50 aA	88.11±0.60 aB	79.49±0.65 bB	50.40±1.14 cB	$F_{3,36} = 580.166$ $P < 0.001$
	柞蚕健康卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the healthy eggs of <i>A. pernyi</i>	89.50±0.32 abA	92.05±0.51 aA	87.88±0.71 bA	88.86±1.06 bA	$F_{3,36} = 6.327$ $P < 0.001$
发育历期 (d) Developmental duration (d)	柞蚕灰卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the gray eggs of <i>A. pernyi</i>	9.64±0.04 aA	9.68±0.03 aA	9.68±0.93 aA	9.77±0.06 aA	$F_{3,36} = 1.840$ $P = 0.157$
	柞蚕健康卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the healthy eggs of <i>A. pernyi</i>	9.58±0.02 bA	9.57±0.02 bB	9.55±0.01 bB	9.64±0.01 aB	$F_{3,36} = 5.907$ $P = 0.002$
后代雌性比 (%) Female proportion of offspring (%)	柞蚕灰卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the gray eggs of <i>A. pernyi</i>	88.67±0.48 bA	88.82±0.43 bA	91.71±0.48 aA	92.43±0.39 aA	$F_{3,36} = 18.970$ $P < 0.001$
	柞蚕健康卵繁育的螟黄赤眼蜂 <i>T. chilonis</i> reared by the healthy eggs of <i>A. pernyi</i>	88.90±0.54 aA	89.20±0.44 aA	88.95±0.53 aB	88.68±0.53 aB	$F_{3,32} = 0.178$ $P = 0.911$

表中数据为平均值±标准误。不同小写字母表示同行数据差异显著 ($P < 0.05$, Tukey's HSD 检验), 不同大写字母表示同列数据差异显著 ($P < 0.05$, Tukey's HSD 检验)。
Data in the table are means±SE. Different lowercase letters in the same row and different uppercase letters in the same column indicate significant difference ($P < 0.05$, Tukey's HSD test).

(Huger, 1984; Sajap and Lewis, 1988)。在本研究中, 柞蚕灰卵繁育的子代赤眼蜂在寄生冷藏 0-3 d 的米蛾卵后, 其寄生量均低于健康卵繁育的子代赤眼蜂寄生量。总的来看, 柞蚕灰卵繁育的子代赤眼蜂在寄生米蛾卵后, 其寄生量和羽化率均低于柞蚕健康卵繁育的子代赤眼蜂的相应指标。也有部分研究显示, 如果寄生蜂在感病寄主中能够发育成熟, 其寄生能力并不会受到影响, 菜蛾绒茧蜂 *Cotesia plutellae* 寄生小菜蛾 *Plutella xylostella* 幼虫 (被多杀菌素感染) 后, 其子代蜂的寄生能力并未受到影响 (李增梅等, 2005); 斑痣悬茧蜂 *Meteorus pulchricornis* 寄生斜纹夜蛾 *Spodoptera litura* (被短稳杆菌感染) 后, 则对寄生蜂的生长发育不利, 如果寄生蜂能够发育到成虫羽化, 寄生蜂的生殖力不会受到显著的影响 (王以一等, 2014), 而在本研究中, 螟黄赤眼蜂寄生柞蚕灰卵后, 其子代蜂的寄生能力受到不利影响。

昆虫病原菌影响寄生蜂种群的存活及生长发育 (刘君, 2013; 马月, 2019)。苏云金芽胞杆菌感染了斑痣悬茧蜂和绒茧蜂 *Cotesia kazak* sp., 延缓了寄生蜂的生长发育过程, 进而延长了寄生蜂的发育历期 (Walker *et al.*, 2007); 在本研究中柞蚕灰卵繁育的子代赤眼蜂在寄生不同冷藏时间的米蛾卵后, 子代赤眼蜂发育历期延长, 其原因具有类同之处。有研究表明, 螟黄赤眼蜂寄生冷藏 15 d 的米蛾卵后, 其子代蜂的羽化率和雌性比均高于寄生未冷藏米蛾卵的羽化率和雌性比, 其原因可能是卵内物质经过冷藏后产生了更适合赤眼蜂寄生的变化, 从而使螟黄赤眼蜂雌蜂更喜欢在经冷藏过一段时间后的米蛾卵上产卵 (易帝玮等, 2014)。本研究中提供冷藏 2 和 3 d 的米蛾卵时, 柞蚕灰卵繁育的子代赤眼蜂在米蛾卵的雌性比显著升高。某些情况下, 病原微生物不仅会影响寄生蜂的寄生能力, 还会进一步影响寄生蜂的控害潜能 (古德就等, 1991)。研究发现, 螟黄赤眼蜂寄生柞蚕灰卵后, 其子代蜂的寄生能力受到不利影响, 但是赤眼蜂的控害潜能是否受到影响尚不清楚。细菌、真菌、病毒等病原菌与寄生蜂的相关性需要进一步研

究 (马月, 2019)。通过探究柞蚕灰卵繁育的螟黄赤眼蜂对米蛾卵的寄生能力和发育适合度, 发现子代赤眼蜂在米蛾卵上的寄生量、羽化率显著降低, 发育历期延长, 明确指出柞蚕灰卵对子代赤眼蜂产生的不利影响。

对多种害虫而言, 粘质沙雷菌具有较强的致病性, 这也说明其具备较高的生物防治潜力。研究表明, 粘质沙雷菌对一些鳞翅目害虫有毒力作用, 包括烟芽夜蛾 *Heliothis virescens*、烟青虫 *Heliothis assulta*、菜青虫 *Pieris rapae*、棉铃虫 *Helicoverpa armigera*、小菜蛾 (Sikowski and Lawrence, 1998; 陈秀为等, 2005); 大量研究数据表明, 粘质沙雷菌能够侵染多种昆虫, 其细菌本身及产生的代谢产物均具有较强的生物防治潜能 (Bulla *et al.*, 1975; Lauzon *et al.*, 2003; 徐红革和彭辉银, 2004; Parani *et al.*, 2011)。今后有必要对柞蚕灰卵 (病原菌为粘质沙雷菌) 繁育螟黄赤眼蜂的生物防治潜能开展深入研究。

参考文献 (References)

- Beegle CC, Oatman ER, 1975. Effect of a nuclear polyhedrosis virus on the relationship between *Trichoplusia ni* (Lepidoptera: Noctuidae) and the parasite, *Hyposoter xiguae* (Hymenoptera: Ichneumonidae). *Journal of Invertebrate Pathology*, 25(1): 59-71.
- Bian Q, Wang GJ, Nong XQ, Gao S, Qin WQ, Li H, Zhang ZH, 2010. Control of *Brontispa longissima* by *Metarhizium anisopliae* and *Ascodes hispinarum*. *Chinese Journal of Biological Control*, 26(1): 30-34. [边强, 王广君, 农向群, 高松, 覃伟权, 李洪, 张泽华, 2010. 绿僵菌与椰甲截脉姬小蜂对椰心叶甲的协同控制作用. 中国生物防治学报, 26(1): 30-34.]
- Bulla LAJ, Rhodes RA, Julian GS, 1975. Bacteria as insect pathogens. *Annual Review of Microbiology*, 29: 163-190.
- Chen RZ, Li XY, Shi ZF, Fan LL, Zheng HB, Sun GZ, 2007. Preliminary study on biology characteristic and control effect on *Ostrinia furnalis* Guenee of *Trichogramma dendrolimi* carrying Bt. *Journal of Jilin Agricultural University*, 29(3): 259-261. [陈日翌, 李秀岩, 石钟锋, 范莉莉, 郑红兵, 孙光芝, 2007. 载菌赤眼蜂生物学特性及其对亚洲玉米螟防治效果的初步研究. 吉林农业大学学报, 29(3): 259-261.]
- Chen XW, Fan H, Zhou K, Lan HX, Sun BZ, 2005. Study on the toxicity of *Serratia marcescens* to the common vegetable insects.

- Tianjin Agricultural Sciences, 11(3): 5–7. [陈秀为, 范寰, 周可, 兰洪霞, 孙伯芝, 2005. 一株粘质沙雷氏菌对蔬菜常见害虫毒力的研究. 天津农业科学, 11(3): 5–7.]
- Du WM, Xu J, Hou YY, Lin Y, Zang LS, Yang XB, Zhang JJ, Ruan CC, Desneux N, 2018. *Trichogramma* parasitoids can distinguish between fertilized and unfertilized host eggs. *Journal of Pest Science*, 91(2): 771–780.
- Gu DJ, Yu ME, Hou RH, Li ZH, 1991. The effects of sublethal doses of insecticides on the foraging behaviour of parasitoid, *Diaeretiella rapae* (Hym. Braconidae). *Acta Ecologica Sinica*, 11(4): 324–330. [古德就, 余明恩, 侯任环, 李哲怀, 1991. 农药亚致死剂量对菜蚜茧蜂搜索行为影响的研究. 生态学报, 11(4): 324–330.]
- Guo Z, Ruan CC, Zang LS, Zhang F, Jin FY, 2012. Design of specific primer for *Trichogramma japonicum* based on rDNA-ITS2 and application of diagnostic primers in identification of four *Trichogramma* species. *Chinese Journal Rice Science*, 26(1): 123–126. [郭震, 阮长春, 臧连生, 张帆, 靳锋云, 2012. 稻螟赤眼蜂 rDNA 特异引物设计及诊断引物在赤眼蜂分子鉴定中的应用. 中国水稻科学, 26(1): 123–126.]
- Hafez M, Salama PHS, Aboul-Ela R, Zaki PDFN, Ragaei M, 1997. *Bacillus thuringiensis* affecting the larval parasite *Meteorus laeiventris* Wesm. (Hym., Braconidae) associated with *Agrotis ypsilon* (Rott.) (Lep., Noctuidae) larvae. *Journal of Applied Entomology*, 121(1/5): 535–538.
- Huger AM, 1984. Susceptibility of the egg parasitoid *Trichogramma evanescens* to the microsporidium *Nosema pyrausta* and its impact on fecundity. *Journal of Invertebrate Pathology*, 44(2): 228–229.
- Irabagon TA, Brooks WM, 1974. Interaction of *Campoletis sonorensis* and a nuclear polyhedrosis virus in larvae of *Heliothis virescens*. *Journal of Economic Entomology*, 67(2): 229–231.
- Jiang JX, Zeng AP, Ji XY, Jiang ZR, 2005. Vertical transmission of *Spodoptera exigua* nuclear polyhedrosis virus in the beet armyworm *Spodoptera exigua*. *Acta Entomologica Sinica*, 48(6): 922–927. [蒋杰贤, 曾爱平, 季香云, 蒋祝瑞, 2005. 甜菜夜蛾核型多角体病毒在宿主种群中的垂直传播研究. 昆虫学报, 48(6): 922–927.]
- Kaya HK, Tanada Y, 1973. Hemolymph factor in armyworm larvae infected with a nuclear-polyhedrosis virus toxic to *Apanteles militaris*. *Journal of Invertebrate Pathology*, 21(3): 211–214.
- Lauzon CR, Bussert TG, Sjogren RE, 2003. *Serratia marcescens* as a bacterial pathogen of *Rhagoletis pomonella* flies (Diptera: Tephritidae). *European Journal of Entomology*, 100(1): 87–92.
- Li YX, Liu SS, Yu JP, Lou QP, Tang ZH, 2002. Lethal and sublethal effects of fenvalerate applied to host larvae on the parasitoid *Cotesia plutellae*. *Journal of Plant Protection*, 29(3): 217–222. [李元喜, 刘树生, 余建平, 楼巧萍, 唐振华, 2002. 氰戊菊酯施用于寄主幼虫对菜蛾绒茧蜂的致死和亚致死效应. 植物保护学报, 29(3): 217–222.]
- Li ZM, Liu YQ, Liu SS, 2005. Lethal and sublethal effects of spinosad on the parasitoid *Cotesia plutellae*. *Chinese Journal of Pesticide Science*, 7(1): 24–28. [李增梅, 刘银泉, 刘树生, 2005. 多杀菌素对菜蛾绒茧蜂的致死和亚致死效应. 农药学报, 7(1): 24–28.]
- Liu J, 2013. The effect of *Spodoptera exigua* nuclear polyhedrosis virus (SeNPV) on the growth and development of *Microplitis pallidipes* Szepligeti and on the endocrine activity of host larvae. Master dissertation. Shanghai: Shanghai Ocean University. [刘君, 2013. 甜菜夜蛾核型多角体病毒对淡色侧沟茧蜂生长发育及寄主内分泌活动的影响. 硕士学位论文. 上海: 上海海洋大学.]
- Ma Y, 2019. Preliminary identification of pathogen causing gray eggs of *Antheraea pernyi* and its effects on host selection and suitability of *Trichogramma dendrolimi*. Master dissertation. Changchun: Jilin Agricultural University. [马月, 2019. 柞蚕灰卵病原菌的初步鉴定及对松毛虫赤眼蜂寄生选择适应性的影响. 硕士学位论文. 长春: 吉林农业大学.]
- Mason PG, Erlandson MA, Elliott RH, Harris BJ, 2002. Potential impact of spinosad on parasitoids of *Mamestra configurata* (Lepidoptera: Noctuidae). *The Canadian Entomologist*, 134(1): 59–68.
- Mohan M, Sushil SN, Bhatt JC, Gujar GT, Gupta HS, 2008. Synergistic interaction between sublethal doses of *Bacillus thuringiensis* and *Campoletis chlorideae* in managing *Helicoverpa armigera*. *BioControl*, 53(2): 375–386.
- Nan N, 2014. Pathogen identification and their sensitivity to bactericides for bacterial diseases on five medicinal plants in Jilin Province. Master dissertation. Changchun: Jilin Agricultural University. [南楠, 2014. 吉林省 5 种药用植物细菌病害的病原鉴定及对药剂的敏感性研究. 硕士学位论文. 长春: 吉林农业大学.]
- Parani K, Shetty GP, Saha BK, 2011. Isolation of *Serratia marcescens* SR1 as a source of chitinase having potentiality of using as a biocontrol agent. *Indian Journal of Microbiology*, 51(3): 247–250.
- Peng HY, Chen XW, Jiang Y, Shen RJ, Zhou XM, Hu ZH, 1998. Controlling *Dendrolimus punctatus* with *Trichogramma dendrolimi* carrying cytoplasmic polyhedrosis virus. *Chinese Journal of Biological Control*, 14(3): 11–14. [彭辉银, 陈新文,

- 姜芸, 沈瑞菊, 周显明, 胡志红, 1998. 松毛虫赤眼蜂携带质型多角体病毒防治马尾松毛虫. 中国生物防治学报, 14(3): 11–14.]
- Ruan CC, Zhu XY, Meng ZJ, Su RJ, 2000. Influences of *Antheraea pernyi* diseases on eggs-host of *Trichogramma*. *Journal of Jilin Agricultural University*, 22(3): 22–26. [阮长春, 朱兴友, 孟昭军, 苏仁君, 2000. 柞蚕蛾病害与赤眼蜂柞蚕寄主卵的关系. 吉林农业大学学报, 22(3): 22–26.]
- Sajap AS, Lewis LC, 1988. Effects of the microsporidium *Nosema pyrausta* (Microsporidia: Nosematidae) on the egg parasitoid, *Trichogramma nubilale* (Hymenoptera: Trichogrammatidae). *Journal of Invertebrate Pathology*, 52(2): 294–300.
- Schneider MI, Smagghe G, Gobbi A, Viñuela E, 2003. Toxicity and pharmacokinetics of insect growth regulators and other novel insecticides on pupae of *Hyposoter didymator* (Hymenoptera: Ichneumonidae), a parasitoid of early larval instars of lepidopteran pests. *Journal of Economic Entomology*, 96(4): 1054–1065.
- Sikorowski PP, Lawrence AM, 1998. Transmission of *Serratia marcescens* (Enterobacteriaceae) in adult *Heliothis virescens* (Lepidoptera: Noctuidae) laboratory colonies. *Biological Control*, 12: 50–55.
- Smith SM, 1996. Biological control with *Trichogramma*: Advances, successes, and potential of their use. *Annual Review of Entomology*, 41: 375–406.
- Sun GZ, Zhang JJ, Ruan CC, 2005. Studies on the control of *Ostrinia furnacalis* by using pathogenic bacterium carried by *Trichogramma dendrolimi*. *Journal of Jilin Agricultural Sciences*, 30(3): 3–5. [孙光芝, 张俊杰, 阮长春, 2005. 携菌赤眼蜂防治亚洲玉米螟效果的研究. 吉林农业科学, 30(3): 3–5.]
- Walker GP, Cameron PJ, MacDonald FM, Madhusudhan VV, Wallace AR, 2007. Impacts of *Bacillus thuringiensis* toxins on parasitoids (Hymenoptera: Braconidae) of *Spodoptera litura* and *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Biological Control*, 40(1): 142–151.
- Wang YY, Li BP, Gao XW, Meng L, 2014. Effects of the bacterium *Empedobacter brevis* on development, survival and fecundity in *Meteorus pulchricornis* (Hymenoptera: Braconidae). *Journal of Nanjing Agricultural University*, 37(1): 75–80. [王以一, 李保平, 高小文, 孟玲, 2014. 短稳杆菌对斑痣悬茧蜂发育、存活和生殖力的影响. 南京农业大学学报, 37(1): 75–80.]
- Xu HG, Peng HY, 2004. Delayed effects of chitinase of *Serratia marcescens* S₃ on *Helicoverpa armigera* in different instar. *Acta Microbiologica Sinica*, 44(1): 88–92. [徐红革, 彭辉银, 2004. 沙雷氏杆菌 S₃ 菌株产几丁质酶对棉铃虫不同虫龄幼虫的后致死作用. 微生物学报, 44(1): 88–92.]
- Yi DW, Xiao R, Zhao YL, Li DS, Zhang GR, 2014. Cold storage of *Corcyra cephalonica* eggs affects the quality of *Trichogramma chilonis* offspring. *Journal of Environmental Entomology*, 36(4): 565–571. [易帝玮, 肖榕, 赵云龙, 李敦松, 张古忍, 2014. 冷藏米蛾卵对子代螟黄赤眼蜂质量的影响. 环境昆虫学报, 36(4): 565–571.]
- Zhao LN, Ma Y, Yang XB, Iqbal A, Ruan CC, Zang LS, 2020. Identification of *Serratia marcescens* isolated from *Antheraea pernyi* eggs and determination of bacterial pathogenicity and transmission pathway. *Journal of Invertebrate Pathology*, 169: 107297.
- Zhang J, Wang JL, Yang CC, Zhang F, Xu BM, Zhao DS, Li TH, Zhao XG, Wang GJ, 1990. The effect of long-term releasing of *Trichogramma* on controlling *Ostrinia* in large area. *Journal of Shenyang Agricultural University*, 21(4): 285–290. [张荆, 王金玲, 杨长成, 张凤, 许宝民, 赵德山, 李铁汉, 赵希贵, 王贵钧, 1990. 长期利用赤眼蜂大面积防治玉米螟的效果评价. 沈阳农业大学学报, 21(4): 285–290.]