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延迟交配对马铃薯块茎蛾繁殖力及寿命的影响

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摘要: 为明确延迟交配对马铃薯块茎蛾 *Phthorimaea operculella* 的影响, 在室内条件下, 分别对初羽化未交配的马铃薯块茎蛾雌虫、雄虫及雌雄虫同时延迟 1~5 d 配对饲养, 研究不同延迟交配处理对该虫产卵量、卵的孵化率及雌雄成虫寿命的影响。结果表明, 从产卵量来看, 分别将雄虫或雌虫延迟 1~3 d 交配对产卵量无显著影响, 而延迟 4 和 5 d 交配能显著降低其产卵量, 其中雄虫分别延迟 4 d 和 5 d 交配后使单雌产卵量分别降低了 20.50% 和 42.00%, 雌虫分别延迟 4 d 和 5 d 交配后单雌产卵量分别降低了 26.01% 和 35.79%。当将雌雄同时延迟 1~2 d 交配, 对单雌产卵量无显著影响, 而延迟 3 d、4 d 和 5 d 交配时, 产卵量分别降低了 12.50%、23.84% 和 44.57%。从卵的孵化率来看, 延迟 1~5 d 交配对卵的孵化无明显影响。从成虫寿命来看, 不同延迟交配对雌雄虫的寿命均无显著影响。由此表明, 马铃薯块茎蛾延迟 3 d 或 4 d 后交配有利于降低其产卵量, 因此可通过在田间设置性诱剂以干扰马铃薯块茎蛾正常交配来降低产卵量, 从而达到控制田间马铃薯块茎蛾下一代虫口数量的作用。

关键词: 马铃薯块茎蛾; 延迟交配; 成虫寿命; 繁殖力; 卵孵化率

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Effect of delayed mating on adult longevity and reproduction of *Phthorimaea operculella*

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Abstract: To clarify the effects of delayed mating on potato tuber moth, *Phthorimaea operculella*, the effects of the newly emerged adults of potato tuber moth were reared for 1~5 days on fecundity, hatching rate and longevity of male and female adults were compared after different delayed mating treatments (delayed female, delayed male, delayed female and male) under indoor conditions. The results showed the delay of mating for 1~3 days had no significant effect on the fecundity of both females and males, but the fecundity of males decreased by 20.50% and 42.0%, the delay of females decreased by 26.01% and 35.79% when the mating was delayed for 4 and 5 days, respectively. The simultaneous delay of mating by 1~2 days had no significant effect on the fecundity per female, but when the mating was delayed for 3, 4 and 5 days, the fecundity decreased by 12.50%, 23.84% and 44.57%, respectively. From the

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perspective of egg hatching rate, the delay of 1 ~5 days had no significant effect on egg hatching. In terms of adult longevity, different delayed mating days had no significant effect on the longevity of males and females. The delayed mating for 3 or 4 days was beneficial to reduce the fecundity of potato tuber moth. Therefore, the fecundity of potato tuber moth can be reduced using sex attractants in the field by interfering with the normal mating of potato tuber moth, which can be used to control the population of the next generation of potato tuber moth in the field.

Key words: *Phthorimaea operculella*; delayed mating; adult longevity; fecundity; egg hatching rate

延迟交配是指动物的交配行为在环境中可能受到各种生物或非生物因素的影响,不能正常交配而延迟(杨广明等,2015; Waqas *et al.*, 2020)。如利用性诱剂大量诱杀雄性或采用迷向法以阻止两性间的通讯联系,降低田间雌雄虫之间的交配概率,使其不能在合适的时间完成交配,从而达到控制害虫种群增长的目的(赵信等,2012; 闫俊杰等,2019)。应用这些技术的一个重要前提是必须对某种特定害虫的交配行为有深入的了解,以便于系统评价这些技术在田间的应用前景及效果(王香萍和张钟宁,2004; 孔维娜等,2013)。据报道,不同种类昆虫延迟交配对其种群繁殖及寿命等影响不同,如 Wenninger and Averill (2006) 总结了延迟交配对鞘翅目 Coleoptera、鳞翅目 Lepidoptera、双翅目 Diptera 和同翅目 Hemiptera 等昆虫的影响,发现一些昆虫的繁殖力下降而一些恒定不变。王香萍和张钟宁(2004)总结了延迟交配对鳞翅目昆虫的生殖力、卵的孵化率、交配成功率、成虫寿命等的影响,结果发现在鳞翅目昆虫中,雌虫或雄虫延迟交配均降低雌虫的生殖力、卵的孵化率和交配成功率,但雌雄虫寿命延长。因此,明确延迟交配对于某种特定昆虫种群生物学特性的影响,对于害虫绿色防控具有重要意义。

马铃薯块茎蛾 *Phthorimaea operculella* (Zeller) 又名烟草潜叶蛾、马铃薯麦蛾,是一种世界性分布的毁灭性茄科作物害虫(Rondon, 2010),其对田间马铃薯植株和裸露薯块和仓储的马铃薯薯块均可造成严重危害(Rondon and Xue, 2010)。其寄主植物主要有马铃薯、烟草、番茄、茄子、辣椒等,但对马铃薯和烟草的嗜食性较强(郭志祥等,2014; Vanevagancheva *et al.*, 2016; Aryal and Jung, 2019)。该虫无严格的滞育现象,成虫产卵量大,卵孵化率高,温湿度适宜均可生长发育繁殖,对温度具有较强耐受性(Andreadis *et al.*, 2016)、对传统化学农药具有较强的抗性

(Doğramaci and Tingey, 2010; El-kady, 2011),由此给该害虫的防治带来了巨大的困难。

目前对马铃薯块茎蛾的防治方法主要还是化学防治(Coll *et al.*, 2000; Eivazian *et al.*, 2018)。然而,由于化学农药的广泛使用,该虫已经产生了较强的抗药性,加之马铃薯块茎蛾的寄主植物大多为蔬菜、粮食作物和经济作物,采用化学农药对人畜的危害较大(Doğramaci and Tingey, 2010; Meabed *et al.*, 2011)。因此,为减少化学农药的使用和延缓抗药性的发展,植保科技工作者已在多种生物技术协同进行绿色防控方面进行了大量的研究(Keasar and Steinberg, 2008; Jukes *et al.*, 2014; Yuan *et al.*, 2018),如对马铃薯块茎蛾性信息素(Arab *et al.*, 2007)的筛选和应用其中以(E-4, Z-7)-十三碳二烯乙酸酯(E4, Z7-13: Ac)和(E-4, Z-7, Z-10)-十三碳三烯乙酸酯(E4, Z7, Z10-13: Ac)为主要成分的性信息素在马铃薯块茎蛾种群监测和防治中取得的较好的效果(闫俊杰等,2019)。延迟交配对雌雄两性的性行为习性的影响,将直接关系到使用性信息素防治害虫的效果,延迟交配会对种群的生物学参数产生不同程度的影响,进而影响其适合度(Mori and Evenden, 2013)。然而,延迟交配是否会影响马铃薯块茎蛾的寿命和繁殖力,目前未见相关研究报道。

因此,本研究通过探讨马铃薯块茎蛾延迟交配对马铃薯块茎蛾雌虫的生殖能力、卵的孵化率和成虫寿命的具体影响,为利用性信息素防治马铃薯块茎蛾提供参考和依据。

1 材料与方法

1.1 虫源饲养

马铃薯块茎蛾幼虫采集于云南省宣威市板桥镇(N26°05'52.3", E104°04'27.5")马铃薯田。室内参照Rondon(2010)的饲养方法进行饲养。首先在有机玻璃透明养虫箱(长×宽×高=40 cm×

40 cm × 40 cm) 内铺一薄层消毒细沙, 然后在其上放置一层新鲜马铃薯薯块, 将采集的幼虫放置于薯块上, 任其繁殖。获得稳定种群后, 大量收集同一天的卵, 待其孵化后将幼虫挑到另外的新鲜马铃薯薯块上饲养。幼虫化蛹后将蛹收集于指形管 (直径 R 2.5 cm, 高 H 8 cm) 中, 每管 1 头, 顶部用 2 层纱布封口, 置于人工气候箱 (恒立仪器有限公司, 型号为 RG-300) 中, 温度 26℃, 湿度为 70%, 光照时间 16 h, 待其羽化后供后续试验所用。

1.2 马铃薯块茎蛾雌雄成虫同时延迟交配对生殖的影响

将羽化 0, 1, 2, 3, 4 和 5 d 的未交尾马铃薯块茎蛾雌雄成虫分别单对配对 (雌: 雄 = 1:1) 置于指形管中, 顶部用 2 层纱布封口, 再在其上添加 5% 蜂蜜水, 供成虫取食。自配对后, 每 24 h 统计一次马铃薯块茎蛾雌虫的产卵数量, 然后再统计卵的孵化率, 依次观察直至马铃薯块茎蛾死亡, 统计马铃薯块茎蛾雌雄虫的寿命, 每处理 10 个重复。

1.3 马铃薯块茎蛾雌虫延迟交配对生殖的影响

将羽化 1, 2, 3, 4 和 5 d 未交尾的马铃薯块茎蛾雌虫与羽化 0 d 未交尾的雄虫分别单对配对 (雌: 雄 = 1:1) 置于指形管中, 处理同上。自配对后, 每 24 h 统计一次马铃薯块茎蛾雌虫的产卵数量, 然后再统计卵的孵化率, 依次观察直至马铃薯块茎蛾死亡, 统计马铃薯块茎蛾雌雄虫的寿命, 每处理 10 个重复。

1.4 马铃薯块茎蛾雄虫延迟交配对生殖的影响

将羽化 1, 2, 3, 4 和 5 d 未交尾的马铃薯块茎蛾雄虫与羽化 0 d 未交尾的雌虫分别单对配对 (雌: 雄 = 1:1) 置于指形管中, 处理同上。自配对后, 每 24 h 统计一次马铃薯块茎蛾雌虫的产卵数量, 然后再统计卵的孵化率, 依次观察直至马铃薯块茎蛾死亡, 统计马铃薯块茎蛾雌雄虫的寿命, 每处理 10 个重复。

1.5 数据分析

数据采用 Excel 2010 对原始数据进行整理, 采用 SPSS 20.0 进行差异分析, 然后采用 R 语言 (R4.0.0) ggplot2 软件作图。同一延迟交配模式下不同延迟时间的雌或雄成虫寿命、雌成虫产卵量及卵的孵化率之间的差异性检验采用 Tukey HSD 检验, 同一延迟交配模式下不同延迟时间两组之间的雌或雄成虫寿命、雌成虫产卵量及卵的孵化率的差异检验采用 T 检验。

2 结果与分析

2.1 延迟交配对马铃薯块茎蛾成虫寿命的影响

在雄虫延迟模式下 (表 1), 雌虫的寿命随延迟时间延长, 有缩短趋势, 但未达显著水平 ($F = 0.13, P > 0.05$), 雄虫寿命之间无显著差异 ($F = 0.048, P > 0.05$); 雌虫延迟模式下 (表 1), 雌雄虫寿命均无显著差异 (雌: $F = 0.226, P > 0.05$; 雄: $F = 0.128, P > 0.05$); 雌雄同时延迟交配模式下 (表 1), 随延迟时间的延长, 雌雄虫寿命也无显著差异 (雌: $F = 0.029, P > 0.05$; 雄: $F = 0.130, P > 0.05$); 未进行交配的雌雄虫寿命均显著短于其它延迟交配处理下雌雄虫寿命, 其雌雄虫寿命分别为 16.70 ± 0.78 d 和 9.30 ± 1.00 d (雌: $F = 2.397, P < 0.05$; 雄: $F = 5.756, P < 0.05$)。

2.2 延迟交配对产卵量的影响

在雄虫延迟模式下 (图 1), 雄虫延迟 1~5 d 交配, 雌虫的单雌产卵量分别为 123.10 ± 7.83 、 120.70 ± 7.80 、 126.50 ± 7.61 、 102.20 ± 12.78 和 74.70 ± 6.63 粒, 与对照组 128.80 ± 8.78 粒相比, 延迟 1~3 d 单雌产卵量无显著差异 ($F = 1.801, P > 0.05$)。而延迟 4~5 d 的单雌产卵量与对照组相比显著降低, 第 4 和 5 天分别降低 20.50% 和 42.00% ($F = 1.42, P < 0.05$; $F = 2.631, P < 0.05$)。

在雌虫延迟模式下 (图 1), 雌虫延迟 1~5 d 交配, 雌虫的单雌产卵量分别为 137.10 ± 14.97 、 124.40 ± 6.42 、 122.90 ± 12.64 、 95.30 ± 13.54 、 82.70 ± 13.70 粒。延迟交配 1~3 d 单雌产卵量与对照组无显著差异 ($F = 2.917, P > 0.05$)。而延迟 4~5 d 的单雌产卵量与对照组相比显著降低, 延迟第 4 和 5 天分别降低 26.01% 和 35.79% ($F = 4.852, P < 0.05$; $F = 9.957, P < 0.05$)。

在雌雄虫同时延迟交配模式下 (图 1), 雌雄虫同时延迟 1~5 d, 雌虫的单雌产卵量分别为 120.30 ± 9.10 、 127.40 ± 8.22 、 112.70 ± 13.30 、 98.10 ± 9.78 、 71.40 ± 9.04 粒。延迟交配 1~2 d 雌虫单雌产卵量与对照组无显著差异 ($F = 2.464, P > 0.05$)。而延迟 3~5 d, 单雌产卵量与对照组相比显著降低, 分别降低 12.50%、23.84% 和 44.57% ($F = 3.639, P < 0.05$; $F = 0.014, P < 0.05$; $F = 3.383, P < 0.05$)。

表 1 延迟交配对马铃薯块茎蛾成虫寿命的影响
Table 1 Effect of delayed mating on adult longevity of *Phthorimaea operculella*

处理 Treatments	延迟天数 (d) Days delayed	雌虫寿命 (d) Female longevity	雄虫寿命 (d) Male longevity
雄虫延迟 Delayed male	1	28.50 ± 9.30 Aa	33.50 ± 6.09 Aa
	2	26.50 ± 12.62 Aa	32.00 ± 7.22 Aa
	3	25.90 ± 13.16 Aa	32.70 ± 9.59 Aa
	4	25.60 ± 10.75 Aa	32.80 ± 8.44 Aa
	5	25.20 ± 4.07 Aa	32.00 ± 10.93 Aa
雌虫延迟 Delayed female	1	27.50 ± 4.82 Aa	32.50 ± 2.69 Aa
	2	27.70 ± 4.05 Aa	32.70 ± 5.85 Aa
	3	26.30 ± 6.20 Aa	31.30 ± 6.81 Aa
	4	25.70 ± 9.33 Aa	31.40 ± 4.63 Aa
	5	25.80 ± 3.37 Aa	31.90 ± 5.56 Aa
雌雄同时延迟 Delayed male and female	1	26.70 ± 5.48 Aa	32.90 ± 4.81 Aa
	2	27.30 ± 6.36 Aa	30.70 ± 5.39 Aa
	3	26.70 ± 4.34 Aa	32.10 ± 6.71 Aa
	4	26.20 ± 8.73 Aa	31.00 ± 10.02 Aa
	5	26.60 ± 8.81 Aa	30.80 ± 9.66 Aa
对照 Control		26.90 ± 3.08 a	31.30 ± 8.88 a
未交配 Unmated		16.70 ± 0.78 b	9.30 ± 1.00 b

注: 表中大写字母代表同一延迟交配模式下不同延迟时间雌雄虫寿命的差异分析 (Tukey HSD); 小写字母代表不同延迟模式与未交配雌雄虫的差异分析。Note: The majuscules in the table represented difference analysis between male and female in same mating patterns and different delayed time; the minuscules in the table represented difference analysis between male and female in different mating patterns (Tukey HSD).

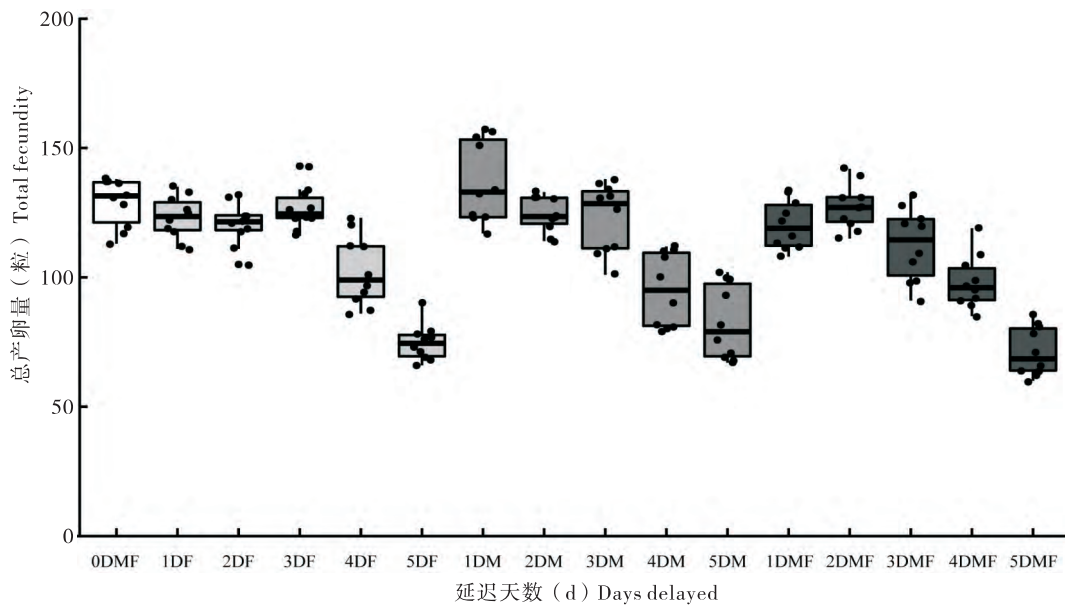


图 1 延迟交配对马铃薯块茎蛾总产卵量的影响

Fig. 1 Effect of delayed mating on total fecundity of *Phthorimaea operculella*

注: DMF, 雌雄虫同时延迟; DF, 雌虫延迟; DM, 雄虫延迟。图 2 同。Note: DMF, Delayed male and female; DF, Delayed female; DM, Delayed male. Same to Fig. 2.

2.3 延迟交配对马铃薯块茎蛾卵的孵化率的影响

雄虫延迟交配 1~5 d 后代孵化率 (图 2) 分别为 86.31%、88.70%、90.42%、88.05% 和 89.30%，各组间无显著差异 ($F = 1.143, P > 0.05$)；雌虫延迟交配 1~5 d 后代孵化率 (图 2) 分别为 82.21%、82.61%、84.92%、81.6% 和

79.87%，各组间均无显著差异 ($F = 1.143, P > 0.05$)；雌雄同时延迟交配 1~5 d 幼虫孵化率 (图 2) 分别为 85.53%、85.70%、85.70%、84.92% 和 85.47%，各组间也无显著差异 ($F = 0.778, P > 0.05$)。

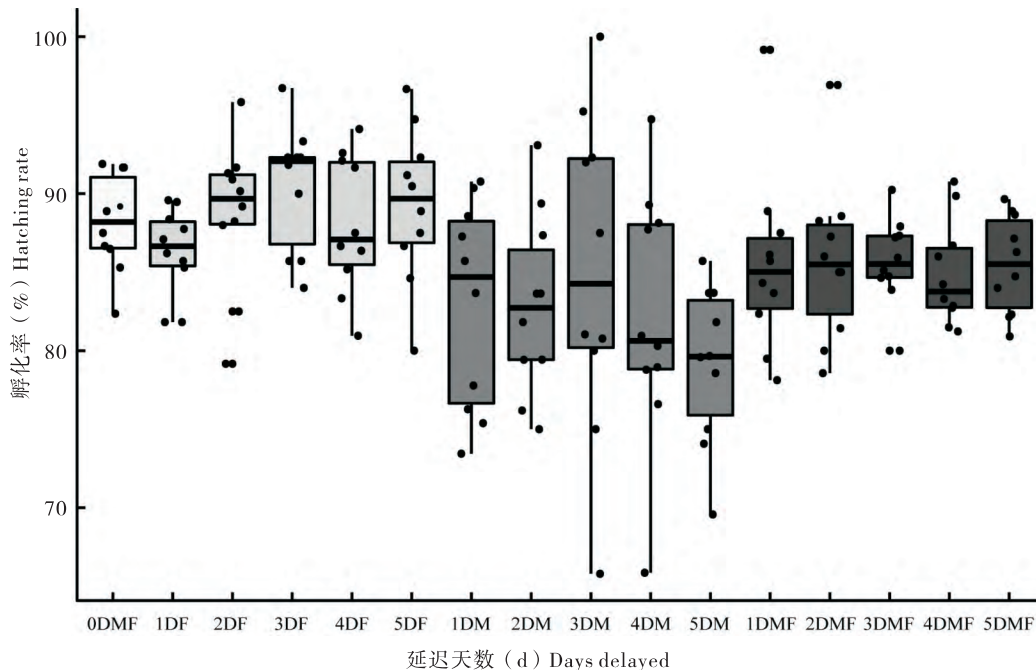


图 2 延迟交配对马铃薯块茎蛾卵的孵化率的影响

Fig. 2 Effect of delayed mating on egg hatching rate of *Phthorimaea operculella*

3 结论与讨论

延迟交配行为对昆虫种群繁殖的影响，是合理应用性信息素的重要依据和参数。本研究发现，无论何种延迟交配模式，对马铃薯块茎蛾的雌雄成虫寿命均无显著影响。这与马铃薯甲虫 *Lasioderma serricorne* (Amoah *et al.*, 2019)、西花蓟马 *Frankliniella occidentalis* Pergande (杨广明等, 2015)、东方丽金龟 *Anomala orientalis* (Wenninger and Averill, 2006)、稻纵卷叶螟 *Cnaphalocrocis medinalis* (Kawazu *et al.*, 2014) 和朱红毛斑蛾 *Phauda flammans* (Zheng *et al.*, 2020) 等昆虫的研究结果一致，即成虫寿命不随交配时间的推迟而变化。而一些昆虫如葡萄花翅小卷蛾 *Lobesia botrana* (Torres-Vila *et al.*, 2002)、山楂叶螨 *Tetranychus viennensis* (李定旭等, 2009)、玉米蛀茎褐夜蛾 *Busseola fusca* (Unnithan and Paye, 1990) 和扶桑绵粉蚧 *Phenacoccus solenopsis* Tinsley (Waqas

et al., 2020) 其成虫寿命随着交配日龄的增加，其雌雄虫寿命显著延长，Torres-Vila 等 (2002) 人认为成虫寿命延长是因为延迟交配降低了繁殖所需的消耗，分配较少的营养用于产卵，从而使多出来的能量重新分配用于维持生命，雌虫还可以重新吸收来自卵的营养物质用于维持生命，所以成虫寿命显著延长。也有一些研究表明，延迟交配同样也会降低成虫的寿命 (Bakker *et al.*, 2011; Ricciardi *et al.*, 2019)，并认为经历交配延迟的雌虫会在受精后立即将它们的资源分配给卵子，从而降低它们的整体寿命 (Loof, 2011)。由此表明，延迟交配对昆虫寿命的影响因昆虫种类的不同而有所差异。此外，本研究发现未交配雌雄成虫的寿命显著短于正常交配和延迟交配下雌雄成虫的寿命，这可能是由于马铃薯块茎蛾因延迟交配为寻找配偶而活动较为活跃，消耗了大量的能量和营养物质，也可能由于内生殖系统衰老导致其寿命缩短。

本研究表明，马铃薯块茎蛾在 3 种延迟交配

模式下,随延迟时间增长,雌虫的单雌产卵量呈下降趋势。单一雌虫延迟交配和单一雄虫延迟交配模式下,延迟第4~5天时单雌产卵量显著降低,而雌雄虫同时延迟交配模式下,在第3天时单雌产卵量就开始显著降低,说明雌雄虫同时延迟交配对单雌产卵量的影响较大。该结果与大多数鳞翅目昆虫延迟交配对产卵量的影响结果一致,如棉褐环野螟 *Haritalodes derogat* (张清泉等,2012)、葡萄花翅小卷蛾 (Torres *et al.*,2002)、稻纵卷叶螟 (Kawazu *et al.*,2014) 等。研究普遍认为雌虫延迟交配导致产卵下降是因为雌性卵母细胞发育被抑制、衰老或卵被重新吸收用于维持生命 (Proshold,1996; Huang and Subramanyam,2003),也有人认为可能是卵母细胞发育能力恶化妨碍了精子的移动导致不能正常受精或产卵前产生了大量的未受精卵 (Kawazu *et al.*,2014);当雄蛾延迟交尾后会导致其生殖附腺逐渐衰退,形成的精子数量减少且质量下降,进而会降低其受精的成功率 (Huang and Subramanyam,2003)。而且在雌雄交尾时,雄蛾可以将体内的保幼激素转移给雌蛾,刺激其卵的受精以及增加产卵量,而延迟交配后,雄蛾的保幼激素不能顺利传递给雌蛾,最终降低了雌蛾的产卵量 (陆鹏飞等,2013)。但是对一些昆虫如宽边黄粉蝶 *Eurema hecabe* (Hiroki and Obara,1997) 和 *Dasylepida ishigakiensis* (Hata *et al.*,2014) 的研究中发现,交配日龄不影响雌虫的产卵量。此外,一些研究结果表明,对于具有相对较短的产卵前期和产卵期(卵成熟较快)的害虫,引起延迟交配即可起到防治作用,而对于产卵前期和产卵期相对较长(卵成熟慢)的害虫,引起延迟交配则防治效果较差 (王香萍和张钟宁,2004)。作者前期研究发现,取食不同寄主植物马铃薯块茎蛾的产卵前期仅1.2 d (王文倩等,2020),而本研究发现无论何种延迟交配模式下,延迟第3天或第4天,马铃薯块茎蛾的单雌产卵量就会急剧下降,这一方面说明产卵前期和产卵期的确与延迟交配昆虫的产卵量有关,另一方面也说明应用性信息素来防治马铃薯块茎蛾具有可行性。

本研究发现,在3种交配模式下,延迟交配1~5 d对马铃薯块茎蛾卵的孵化率影响不大,这可能是由于在交配过程中,雄虫有足够的精子可使雌虫的卵变为受精卵来完成后代繁衍。陆鹏飞等(2013)对豆野螟 *Maruca vitrata* 的研究也有相似的结果。

综上所述,在马铃薯块茎蛾防治过程中,可以利用马铃薯块茎蛾延迟交配3~5 d导致产卵量显著下降的特点,应用性信息素使雄虫在合理的时机得到大量诱捕,进而减少马铃薯块茎蛾的子代数量,达到有效防治的目的。而一些研究表明,交配次数也会影响昆虫的寿命和繁殖力(孔维娜等,2013),而且雌雄交配中断、大量诱捕、降雪、降雨、不利的温湿度和风等均能造成昆虫延迟交配 (Cardé and Minks,1995)。因此,对于马铃薯块茎蛾的交配行为观察及其交配延迟的影响因素等还需要进一步研究。

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