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草地贪夜蛾交配行为及繁殖的观察

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摘要:【目的】草地贪夜蛾*Spodoptera furgiperda*(J. E. Smith)是入侵我国的重大农业害虫,对我国粮食生产构成严重威胁。交配行为是两性生殖的昆虫在配偶选择及繁殖后代的过程中最基本最重要的环节之一,在种群繁衍与进化方面也具有重要意义。【方法】在恒温26 ℃,自然日长条件下连续6 d观察统计草地贪夜蛾成虫的交配节律、交配持续期、繁殖力和寿命。【结果】成虫一生能进行多次交配;成虫的交配行为发生在暗期,交配时间出现于19:30—05:30,交配高峰出现在01:00。成虫羽化后的第2晚至第6晚均能进行交配,随着成虫日龄的增加,交配率显著降低;2日龄成虫的交配率为92.18%,6日龄成虫的交配率下降为25.67%。交配持续时间最短22 min,最长达360 min,平均为(94±6)min,交配持续时间随着成虫日龄的增加而显著缩短。交配次数对每雌产卵量、孵化率和成虫寿命均无显著影响。【结论】草地贪夜蛾的交配行为具有明显节律性,成虫日龄对其交配行为有显著影响,交配次数对其繁殖力无显著影响。研究结果为该虫的繁殖生物学、预测预报和防治提供重要的参考信息。

关键词:草地贪夜蛾;交配节律;交配持续期;繁殖力;寿命
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Observations on the Mating Behavior and Fecundity of *Spodoptera furgiperda*

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Abstract:[**Objective**]*Spodoptera frugiperda*(J. E. Smith)is a major agricultural pest that has invaded China and has brought serious threat to food security.Mating behavior is one of the most important steps during the sex selection and reproduction,and also play a critical role in population prosperity and evolution.[**Method**]The mating behavior,fecundity and longevity of the *S. frugiperda* was systematically observed at the 26 ℃ under naturally changed daylengths for 6consecutive days.[**Result**]The results showed that adults mated repeat-

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edly within their lifespan. The mating behavior was observed in the dark period and daily mating activity occurred from 19:30 to 05:30, and peaked at 01:00 o'clock. Both males and females were able to mate from the second night to sixth night, and the mating rate decreased significantly with the increase of adult age. The mating rate of 2-day-old adults was 92.18%, and that of 6-day-old adults decreased to 25.67%. Mating duration ranged from 22 to 360 mins with a mean of (94±6) mins. Mating duration gradually shortened with the increasing adult age. Number of mating had no significant effects on egg production, hatching rate or on the longevity of adults. [**Conclusion**] The mating behavior of the *S. frugiperda* has obvious rhythm. Adult age has significant effects on mating behavior and number of mating has no significant effects on fecundity. This study provides important information for the reproductive biology, prediction and control of the insect.

Keywords: *Spodoptera furgiperda*; mating rhythm; mating duration; fecundity; longevity

【研究意义】交配行为是两性生殖的昆虫在配偶选择及繁殖后代的过程中最基本最重要的环节之一，在种群繁衍与进化方面也具有重要意义[1]。蛾类属典型的两性生殖的昆虫，其繁殖行为复杂多变，一般包括求偶、交配、产卵和抚幼等行为过程[2]。已有研究[3-6]表明，多数昆虫的交配活动表现为24 h的行为节律，蛾类的交配多发生在黄昏和黎明[7]。这种交配活动在时间上的节律性可以降低种间对相同资源的竞争以及保持交配活动的同步性[8]。昆虫的交配行为还受内部生理因素（如成虫日龄、交配经历等）和外部生态因素（如温度、光周期、寄主等）的影响[9-12]。两性生殖的昆虫，其生殖策略通常存在差异，雄虫通过与尽量多的雌虫交配，扩大其生殖成功来提高其适应性，而雌虫则是通过增加后代遗传多样性来增加其适应性，因此一次或几次交配就足够使其生殖成功达到最大[13-14]。【前人研究进展】草地贪夜蛾 *Spodoptera furgiperda*（J. E. Smith），属于鳞翅目 Lepidoptera 夜蛾科 Noctuidae，原产于美洲热带和亚热带地区，是重大的迁飞性害虫[15]。2016年入侵中非和西非[16]，2018年扩散至印度及东南亚大部分地区[17]，2019年1月在我国云南首次发现草地贪夜蛾[18]。草地贪夜蛾寄主范围广，目前报道其寄主植物种类达353种[19]，但对不同寄主取食适应性存在差异，该虫取食大豆的适合度低于取食玉米[20]，侵入我国后多在玉米上暴发为害[21]；对温度的适应范围广，17~32 ℃可正常生长发育[22]；雌性先熟，雄蛹发育历期显著长于雌蛹[23]；世代周期短，在28 ℃条件下，30 d左右即可完成一个世代[24-25]；繁殖力强，单头雌虫平均一生可产卵1 500粒，最高可达2 000粒[24]；迁飞能力强，成虫每晚可借助风力定向迁飞100 km[26]，王磊等[27]报道草地贪夜蛾在我国的扩散传播速度为14.03~14.78 km/d。2019年5月草地贪夜蛾首次迁入江西，2020年4月中下旬再次迁入江西，使江西的玉米生产遭受了严重损失。2020年8月田间调查发现，在不进行任何防治的情况下，为害最严重的玉米地，其玉米植株100%受害。

【本研究切入点】草地贪夜蛾自迁入我国以来，对其生物学、适生区、分子鉴定、迁飞行为、防治药剂等进行了一系列研究[28]，但关于该虫的交配行为及其对繁殖的影响仍未见详细的报道。因此，本研究系统观察了草地贪夜蛾的交配行为特性及其对成虫繁殖力和寿命的影响。【拟解决的关键问题】探明草地贪夜蛾的交配节律和交配持续时间，以及交配次数对其产卵量、孵化率和寿命的影响，为进一步开展交配机制研究提供理论基础。

1 材料与方法

1.1 供试虫源和饲养方法

用于试验的草地贪夜蛾 *S. frugiperda* 于2020年6月采自江西南昌玉米地（28°68′N，115°89′E），采集的大龄幼虫单头置于培养皿（直径9 cm，高2 cm）中，用新鲜的玉米叶片饲养至化蛹，待成虫羽化后配对置于保鲜袋中交配产卵，每天收集卵块供试验用。幼虫孵化后，立即接入塑料盒（长16 cm，宽11 cm，高5.5 cm）中，置于通风透光的养虫室自然条件下饲养，幼虫3龄后，单头转入培养皿中饲养至化蛹和成虫羽化。

1.2　交配行为及繁殖的观察

成虫羽化后,于第2天09:00进行配对,此成虫均为前一晚羽化,标记为1日龄,其余日龄以此类推。本试验总共配50对,分为3组,分别由3人同时进行观察,均为同一天羽化的成虫。配对的成虫置于充满空气的保鲜袋中交配,每袋只放1对,袋中放入用10%蜂蜜水湿润的棉球供成虫补充营养,所有成虫都置于恒温26 ℃和自然光照的空调房中,每日更换保鲜袋和棉球。成虫配对后的第2天开始观察交配情况。前期观察试验表明,草地贪夜蛾成虫在白天不进行交配,故观察时间选择在19:30—05:30(天黑后至天亮前)。在此期间,用红布包裹手电筒观察,每30 min观察1次,连续观察6 d[11]。详细记录夜间每一时段的交配数及每对成虫交配开始与结束的时间,以及雌虫产卵量、卵的孵化率和雌、雄虫寿命。在这50对成虫6 d的观察试验中,每天观察到的交配数量分别为46,35,25,13,13,2对。由于第6天仅有2对成虫交配,所以取前5天的观察数据绘制了图1~4和表1。

1.3　交配过程描述

以上配对的50对成虫,连续观察6 d,仔细观察并记录雌雄成虫的交配行为,从雌雄虫配对开始至完成一次交配行为结束,记录雌雄虫交配前、交配过程中及交配后的各种行为。

1.4　数据处理

试验数据采用SPSS19.0进行分析,不同日龄成虫的交配率和交配持续时间差异比较,交配次数对产卵量、孵化率和寿命的影响,采用one-way ANOVA和Duncan's多重比较检验。

2　结果与分析

2.1　交配过程描述

天黑前,雌雄虫相对比较安静,各自处于蛰伏状态。天黑后,雌雄虫逐渐开始活跃起来,雌虫求偶时腹部末端开始上扬,紧接着产卵器外伸及腺体胀大;在雌虫求偶的同时,雄蛾触角摆动,开始爬行,随后振翅飞行向雌虫靠近,显得异常兴奋,抱握器张开并伸向雌虫腹部末端进行交配,交配时尾部相连,交配姿势主要是尾对尾呈"一"字型。雌雄成虫交配时安静不动,交配时间可持续22~360 min。交配结束后,雌雄虫尾部分离,过段时间后,各自开始活动,或爬行或飞行或取食。

2.2　交配节律

50对草地贪夜蛾交配成虫的交配动态见图1。结果表明,交配主要发生在暗期(天黑后至天亮前),在暗期的第6.5小时(01:00)交配率最高,达到20.3%;成虫在不同暗期的交配率存在显著差异($F_{20,84}$=2.935,P<0.05)。从整个晚上来看,交配主要发生在23:00—03:00,交配率为71.7%,23:00时前和03:00时后的交配率分别为21.3%和7.0%。

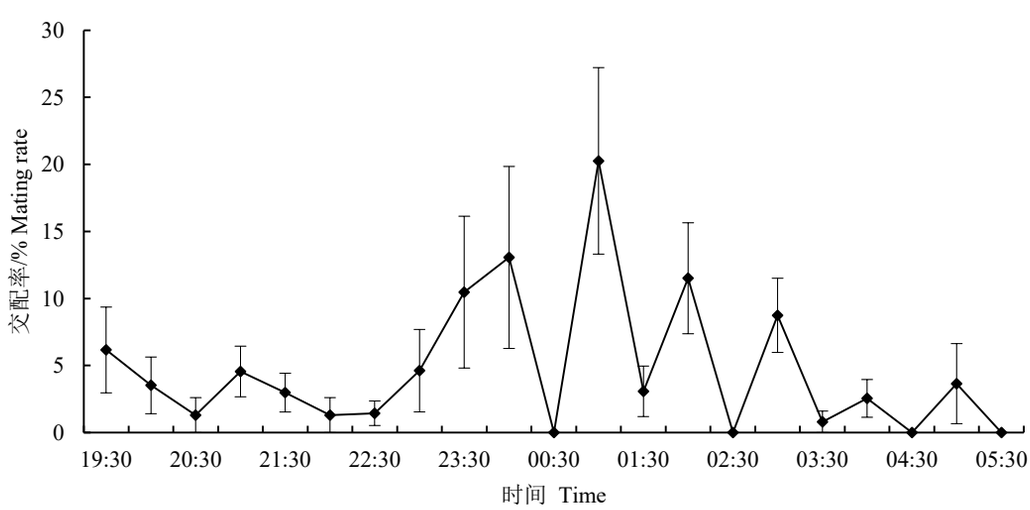
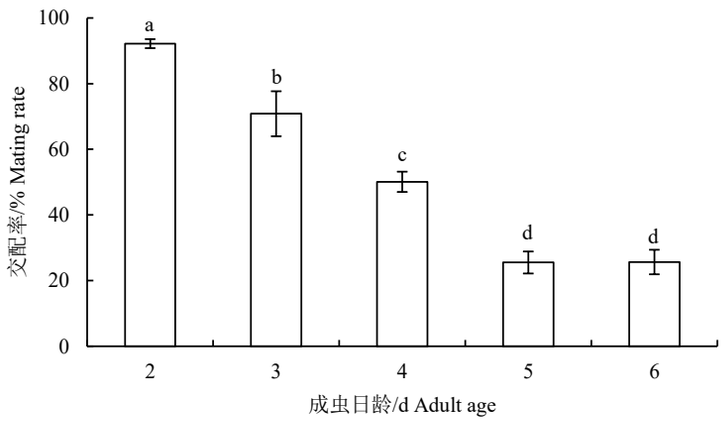


图1　草地贪夜蛾的交配节律

Fig.1　Mating rhythm of the *Spodoptera furgiperda*

2.3 交配率的日龄变化

成虫羽化后的第2天晚上(2日龄)到第6天晚上都可以进行交配(图2)。但不同日龄的成虫交配率存在着明显的差异($F_{4,10}$=50.275,P<0.05),随着成虫日龄的增加,交配率逐渐降低,2日龄成虫的交配率为92.18%,6日龄成虫的交配率下降为25.67%。



误差线表示SE;不同日龄间不同小写字母表示差异显著(one-way ANOVA和Duncan多重比较,P<0.05)。

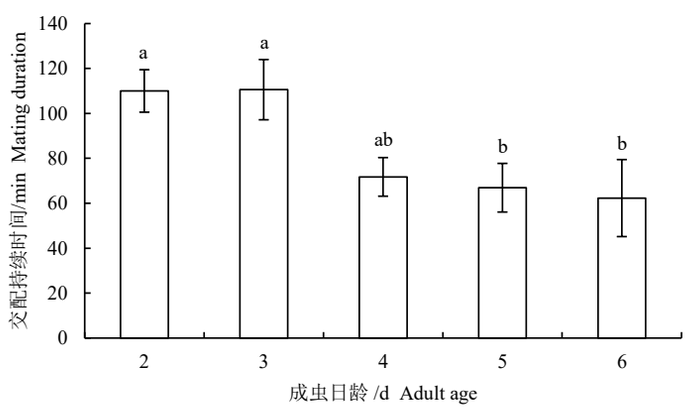
Error bars indicate *SE*. Values with different lowercase letters among adult age are significantly different at 0.05 level based on one-way ANOVA and Duncan's multiple range test.

图2 草地贪夜蛾交配率的日龄变化

Fig.2 The change of mating rate with age in the *Spodoptera furgiperda*

2.4 交配持续时间的日龄变化

成虫日龄对交配持续时间具有显著影响($F_{4,127}$=3.502,P<0.05)。低日龄成虫的交配持续时间较长,但随着成虫日龄的增加,平均交配时间逐渐缩短。2日龄的平均交配持续时间为110.0 min,而6日龄的平均交配持续时间降至62.3 min(图3)。



误差线表示SE;不同日龄间不同小写字母表示差异显著(one-way ANOVA和Duncan多重比较,P<0.05)。

Error bars indicate *SE*. Values with different lowercase letters among adult age are significantly different at 0.05 level based on one-way ANOVA and Duncan's multiple range test.

图3 草地贪夜蛾交配持续时间的日龄变化

Fig.3 The change of mating duration with age in the *Spodoptera furgiperda*

2.5 交配持续时间分布

草地贪夜蛾的交配持续时间个体之间差异很大,最短为22 min,最长可达360 min,平均交配持续时间为(94±6)min。将交配持续时间跨度按30 min一个等级划分时发现(图4),交配持续时间为30~60 min时所占的百分比最高为42.1%,小于30 min和90~120 min所占百分比分别为15.9%和13.5%,其余都在10%以下。

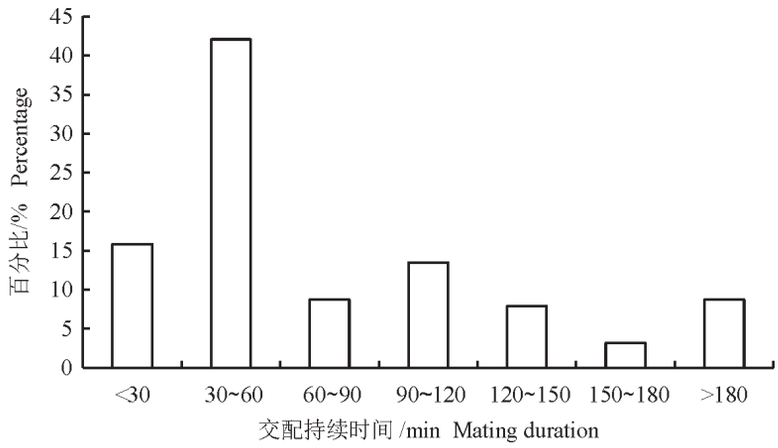


图4　草地贪夜蛾的交配持续时间分布

Fig.4　The distribution of mating duration of the *Spodoptera furgiperda*

2.6　交配次数对产卵量、孵化率和寿命的影响

由表1可知,在连续5 d的观察中,交配3次的雌虫平均产卵量最高,为1 418.33粒,交配1次的雌虫产卵量最低,为1 150.00粒,但方差分析表明,交配次数对每雌产卵量不存在显著差异。交配1次的雌虫产的卵孵化率最低,为87.80%,交配2次的雌虫产的卵孵化率最高,为95.43%,但不同交配次数的雌虫产的卵孵化率无显著差异。交配次数对雌虫寿命和雄虫寿命均无显著影响。

表1　交配次数对草地贪夜蛾产卵量、孵化率和寿命的影响

Tab.1　Effect of number of mating on egg production, hatching rate and longevity of *Spodoptera furgiperda*

交配次数 Number of mating	交配雌虫数 Number of mated females	每雌产卵量/粒 Egg production per female	孵化率/% Hatching rate	雌虫寿命/d Longevity of female	雄虫寿命/d Longevity of male
1	5	1 150.00±252.54[a]	87.80±4.17[a]	10.00±0.55[a]	9.40±0.75[a]
2	4	1 390.00±119.08[a]	95.43±2.28[a]	10.50±2.02[a]	10.25±0.25[a]
3	15	1 418.33±98.76[a]	94.41±1.49[a]	11.00±0.35[a]	10.47±0.39[a]
4	11	1 372.36±170.11[a]	94.34±1.72[a]	11.00±0.57[a]	10.45±0.37[a]
5	3	1 385.00±247.44[a]	92.85±2.33[a]	10.00±0.58[a]	11.00±0.58[a]

表中数据表示平均值±标准误,不同字母表示差异显著(One-way ANOVA 和 Duncan 氏多重比较 $P<0.05$)。

Values (mean±SE) within one row followed by different letters are significantly different at the 0.05 level based on one-way ANOVA and Duncan's multiple tests.

3　结论与讨论

昆虫个体间的交配成功与两性的交配活动以及交配的昼夜节律密切相关,已有研究表明昆虫的交配活动具有昼夜节律性。然而,昆虫种类不同,交配活动节律也差别很大,有些昆虫的交配活动主要发生在白天,如稻绿蝽 *Thyanta pallidovirens*[29]和食蚜瓢虫 *Cheilomenes sexmaculatala*[30];有些种类交配主要发生在下午,如条纹小斑蛾 *Thyrassia penanga*[31-32];而有些昆虫种类如褛裳夜蛾 *Catocala remissa*[33]、甜菜夜蛾 *Spodoptera exigua*[34]和枣黏虫 *Ancylis sativa*[11]等,其交配主要发生在晚上;也有一些种类交配活动发生在整个24 h昼夜循环中,如大猿叶甲 *Colaphellus bowringi*[35]。本试验结果表明,草地贪夜蛾 *S. frugiperda* 的交配主要发生在晚上,并且存在一个明显的交配高峰(01:00)(图1)。

昆虫交配持续期与其成虫交配时的日龄密切相关。有些种类的交配持续期随成虫日龄的增加而延长,如大猿叶甲 *C. bowringi*[35]、地中海实蝇 *Ceratitis capitata*[36]和甜菜夜蛾 *S. exigua*[34]等。有些种类的交配持续期随成虫日龄的增加而缩短,如绿缘扁角叶甲 *Platycorynus parryi*[37]。研究结果表明,草地贪夜蛾的交配持续时间随成虫日龄的增加而逐渐缩短,是交配持续期随成虫日龄的增加而缩短的又一例证。另

外，在自然条件下，连续饲养繁殖了草地贪夜蛾5代，每代配对30对，观察交配情况时发现，每代都有约20%个体延迟交配，交配前期在羽化后5 d以上（正常情况羽化后2 d之内即可交配），推测延迟交配的这些个体可能属于迁飞型个体。因此，下一步工作将系统研究该虫交配与迁飞之间的关系。

多次交配对不同昆虫种类的雌虫精子数量消耗与其产卵量、寿命、孵化率之间的影响各不相同[38-39]。有些昆虫多次交配可以增加雌虫的产卵量，如黑腹果蝇*Drosophila melanogaster*[40]和黄粉虫*Tenebrio molitor*[41]。然而，也有一些昆虫交配次数与产卵量并不相关，如马铃薯甲虫*Leptinotarsa decemlineata*[42]和粉斑螟*Cadra cautella*[43]。交配次数的增加从总体上来说将导致寿命明显缩短，如四纹豆象*Callosobruchus maculatus*[44]和拟暗果蝇*Drosophila pseudoobscura*[45]。另外，也有一些昆虫雌虫的寿命与交配次数无关，如粪蝇*Saltella sphondylli*[46]。本研究结果表明，交配次数对草地贪夜蛾的产卵量、孵化率和寿命均无显著影响。

参考文献 References：

[1] MIYATAKE T.Correlated responses to selection for developmental period in *Bactrocera cucurbitae* (Diptera: Tephritidae): time of mating and daily activity rhythms[J].Behavior genetics, 1997, 27(5): 489-498.

[2] THOMAS M L.Detection of female mating status using chemical signals and cues[J].Biological reviews, 2011, 86(1): 1-13.

[3] SAKAI T, ISHIDA N.Circadian rhythms of female mating activity governed by clock genes in *Drosophila*[J].Proceedings of the national academy of sciences of the United States of America, 2001, 98(16): 9221-9225.

[4] BAUŽIENE V, BUDA V, BERNOTIENE R.Mating activity of the mammalophilic blackflies *Simulium (Wilhelmia) lineatum* (Meigen, 1804) (Diptera: Simuliidae) under laboratory conditions[J].Acta zoologica lituanica, 2004, 14(4): 34-40.

[5] WANG Q, SHI G L.Mating frequency, duration, and circadian mating rhythm of New Zealand wheat bug *Nysius huttoni* White (Heteroptera: Lygaeidae)[J].New Zealand entomologist, 2004, 27(1): 113-117.

[6] RYMER J, BAUERNFEIND L, BROWN S, et al.Circadian rhythms in the mating behavior of the cockroach, *Leucophaea maderae*[J].Journal of biological rhythms, 2007, 22(1): 43-57.

[7] TOPPER C P.Nocturnal behaviour of adults of *Heliothis armigera* (Hübner) (Lepidoptera: Noctuidae) in the Sudan Gezira and pest control implications[J].Bulletin of entomological research, 1987, 77(3): 541-554.

[8] SAUNDERS D S.Insect clocks[M].3rd ed.Amsterdam: Elsevier, 2002.

[9] MATTHEWS R W, MATTHEWS J R.Insect Behavior[M].New York: Springer, 2010: 341-388.

[10] CALLADO-GALINDO M M, VILA-AYALA P, CASTREJÓN-AYALA F, et al.Effect of age, body weight and multiple mating on *Copitarsiade colora* (Lepidoptera: Noctuidae) reproductive potential and longevity[J].Journal of insect behavior, 2013, 26(6): 860-872.

[11] 韩桂彪，杜家纬，李捷.枣粘虫交配行为生态学研究[J].应用生态学报，2000，11(1)：99-102.
HAN G B, DU J W, LI J.Mating behavioral ecology of *Ancylis sativa* adult[J].Chinese journal of applied eco1ogy, 2000, 11(1): 99-102.

[12] 孙丽娟，戴华国，衣维贤，等.二化螟水稻类群与茭白类群成虫羽化节律和交配节律研究[J].昆虫知识，2002，39(6)：421-423.
SUN L J, DAI H G, YI W X, et al.The adult emergence rhythm and mating rhythm of rice host population and water-oats host population of the rice stem borer, *Chilo suppressalis*[J].Chinese bulletin of entomolog, 2002, 39(6): 421-423.

[13] THORNHILL R, ALCOCK J.The evolution of insect mating systems[M].Cambridge: Harvard University Press, 1983.

[14] SINGH S R, SINGH B N.Male remating in *Drosophila ananassae*: evidence for interstrain variation in remating time and shorter duration of copulation during second mating[J].Zoological science, 2000, 17(3): 389-393.

[15] TODD E L, POOLE R W.Keys and illustrations for the army-worm moths of the noctuid genus *Spodoptera* Guenée from the Western Hemisphere[J].Annals of the entomological society of America, 1980, 73(6): 722-738.

[16] GOERGEN G, KUMAR P L, SANKUNG S B, et al.First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a new alien invasive pest in west and central Africa[J].Plos one, 2016, 11(10):

e0165632.

[17] GANIGER P C, YESHWANTH H M, MURALIMOHAN K, et al. Occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India[J]. Current science, 2018, 115(4): 621-623.

[18] 杨学礼,刘永昌,罗茗钟,等.云南省江城县首次发现迁入我国西南地区的草地贪夜蛾[J].云南农业,2019(1):72.
YANG X L, LIU Y C, LUO M Z, et al. The fall armyworm *Spodoptera frugiperda* was first found to migrate to southwest China in Jiangcheng County, Yunnan Province[J]. Yunnan agriculture, 2019(1): 72.

[19] MONTEZANO D G, SPECHT A, SOSA-GÓMEZ D R, et al. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas[J]. African entomology, 2018, 26(2): 286-300.

[20] 刘伟,徐强,黄丽莉,等.草地贪夜蛾不同季节取食玉米叶和大豆叶生活史特性比较[J].江西农业大学学报,2021,43(5):1032-1043.
LIU W, XU Q, HUANG L L, et al. A Comparison of life-history traits of the fall armyworm *Spodoptera frugiperda* feeding on the corn leaves and the soybean leaves in different seasons[J]. Acta agriculturae universitatis Jiangxiensis, 2021, 43(5): 1032-1043.

[21] 王磊,陈科伟,钟国华,等.重大入侵害虫草地贪夜蛾发生危害、防控研究进展及防控策略探讨[J].环境昆虫学报,2019,41(3):479-487.
WANG L, CHEN K W, ZHONG G H, et al. Progress for occurrence and management and the strategy of the fall armyworm *Spodoptera frugiperda* (Smith)[J]. Journal of environmental entomology, 2019, 41(3): 479-487.

[22] 鲁智慧,和淑琪,严乃胜,等.温度对草地贪夜蛾生长发育及繁殖的影响[J].植物保护,2019,45(5):27-31.
LU Z H, HE S Q, YAN N S, et al. Effects of temperatures on the development and reproduction of fall armyworm (*Spodoptera frugiperda* Smith)[J]. Plant protection, 2019, 45(5): 27-31.

[23] HUANG L L, XUE F S, CHEN C, et al. Effects of temperature on life-history traits of the newly invasive fall armyworm, *Spodoptera frugiperda* in Southeast China[J]. Ecology and evolution, 2021, 11(10): 5255-5264.

[24] PRASANNA B M, HUESING J E, EDDYR, et al. Fall armyworm in Africa: a guide for integrated pest management[M/OL]. [2019-10-10]. https://www.usaid.gov/sites/default/files/documents/1867/Fall-Armyworm-IPM-Guide-for-Africa-Jan-30-2018.

[25] 张红梅,尹艳琼,赵雪晴,等.草地贪夜蛾在不同温度条件下的生长发育特性[J].环境昆虫学报,2020,42(1):52-59.
ZHANG H M, YIN Y Q, ZHAO X Q, et al. The growth and development characteristics of *Spodoptera frugipetda* under different temperature conditions[J]. Journal of environmental entomology, 2020, 42(1): 52-59.

[26] ABRAHAMS P, BATEMAN M, BEALE T, et al. Fall armyworm: impacts and implications for Africa[J]. Outlooks on pest management, 2017, 28(5): 196-201.

[27] 王磊,陈科伟,陆永跃.我国草地贪夜蛾入侵扩张动态与发生趋势预测[J].环境昆虫学报,2019,41(4):683-694.
WANG L, CHEN K W, LU Y Y. Long-distance spreading speed and trend predication of fall armyworm, *Spodoptera frugiperda*, in China[J]. Journal of environmental entomology, 2019, 41(4): 683-694.

[28] XIAO Y T. Research on the invasive pest of fall armyworm (*Spodoptera frugiperda*) in China[J]. Journal of integrative agriculture, 2021, 20(3): 633-636.

[29] WANG Q, MILLAR J G. Reproductive behavior of *Thyantapalli dovirens* (Heteroptera: Pentatomidae)[J]. Annals of the entomological society of America, 1997, 90(3): 380-388.

[30] OMKAR, SINGH K. Rhythmicity in life events of an aphidophagous ladybird beetle, *Cheilomenes sexmaculata*[J]. Journal of applied entomology, 2007, 131(2): 85-89.

[31] 何海敏,黄芳,杨东,等.条纹小斑蛾的生物学特性[J].昆虫知识,2009,46(3):411-414.
HE H M, HUANG F, YANG D, et al. Biological characteristics in *Thyrassia penangae*[J]. Chinese bulletin of entomology, 2009, 46(3): 411-414.

[32] 何海敏,肖亮,傅淑,等.光周期和温度对条纹小斑蛾羽化和交配节律的影响[J].江西农业大学学报,2015,37(6):1011-1015.

HE H M, XIAO L, FU S, et al.Efects of photoperiod and temperature on adult eclosion and mating rhythms of *Thyrassia penangae*(Lepidoptera:Zygaenidae)[J].Acta agriculturae universitatis Jiangxiensis, 2015, 37(6):1011-1015.

[33] 郑海霞,张金桐,宗世祥,等.褛裳夜蛾的交配行为及雄蛾对性腺提取物的反应节律[J].生态学报,2015,35(9):3060-3066.
ZHENG H X, ZHANG J T, ZONG S X, et al.Mating behavior and dynamic rhythm of male response to crude extracts of sex pheromones from females *Catocala remissa* Staudinger[J].Acta ecologica Sinica, 2015, 35(9):3060-3066.

[34] 罗礼智,曹卫菊,钱坤,等.甜菜夜蛾交配行为和能力[J].昆虫学报,2003,46(4):494-499.
LUO L Z, CAO W J, QIAN K, et al.Mating behavior and capacity of the beet armyworm, *Spodoptera exigua* (Lepidoptera: Noctuidae)[J].Acta entomologica Sinica, 2003, 46(4):494 -499.

[35] LIU X P, HE H M, KUANG X J, et al.Mating behavior of the cabbage beetle, *Colaphellus bowringi*(Coleoptera:Chrysomelidae)[J].Insect science, 2010, 17(1):61-66.

[36] FIELD S A., TAYLOR P W, YUVAL B.Sources of variability in copula duration of mediterranean fruit flies[J].Entomologia experimentalis et applicata, 1999, 92(3):271-276.

[37] 何海敏,肖亮,傅淑,等.绿缘扁角叶甲生活史、交配及繁殖的观察[J].应用昆虫学报,2015,52(1):193-199.
HE HM, XIAO L, FU S, et al.Observations on the life history, mating and fecundity of *Platycorynus parryi* Baly[J].Chinese journal of applied entomology, 2015, 52(1):193-199.

[38] TREBITT S, FOWLER K, PARTRIDGE L.An effect ofegg-deposition on the subsequent fertility an remating frequency of female *Drosophila melanogaster*[J].Journal of insect physiology, 1988, 34(8):821-828.

[39] SAKUBAI T.Variation in time to sperm depletion andoviposition pattern in female of *Riptortus clavatus*(Heteroptera:Alydidae)[J].Annals of the enotomological society of America, 1998, 91(5):737-740.

[40] CHAPMAN T, LIDDLE LF, KALB J M, et al.Cost of mating in *Drosophila melanogaster* females is mediated by male accessory gland products[J].Nature, 1995, 373(6511):241-244.

[41] DRNEVICH J M, PAPKE R M, RAUSER C L, et al.Material benefits from multiple mating in female mealworm beetles (*Tenebrio molitor* L.)[J].Journal of insect behavior, 2001, 14(2):215-230.

[42] ORSETTI D M, RUTOWSKI R L.No material benefits, and a fertilization cost, for multiple mating by female leaf beetles[J].Animal behaviour, 2003, 66(3):477-484.

[43] MCNAMARA K B, ELGAR M A, JONES T M.A longevity cost of re-mating but no benefits of polyandry in the almond moth, *Cadra cautella*[J].Behavioral ecology and sociobiology, 2008, 62(9):1433-1440.

[44] TSENG H B, YANG R L, LIN C B.The function ofmultiple mating in oviposition and egg maturation in theseed beetle *Callosobruchus maculatus*[J].Physiological entomology, 2007, 32(2):150-156.

[45] TURNER M E.Multiple mating, sperm competition andthefertility component of fitness in *Drosophila pseudoobscura*[J].Florida entomologist, 1986, 69(1):121-128.

[46] MARTIN O Y, HOSKEN D J.Copulation reduces male but not female longevity in *Saltella sphondylli* (Diptera:Sepsidae)[J].Journal of evolutionary biology, 2004, 17(2):357-362.