

草地贪夜蛾的天敌昆虫资源、应用现状及存在的问题与建议

陈万斌, 李玉艳, 王孟卿, 刘晨曦, 毛建军, 陈红印, 张礼生*

(中国农业科学院植物保护研究所/中美合作生物防治实验室, 北京 100193)

摘要: 草地贪夜蛾 *Spodoptera frugiperda* (J. E. Smith) 是原产于美洲热带和亚热带地区的重大农业害虫, 具有迁飞快、寄主广、繁殖强、为害重、适生力强等特点。自 2019 年初入侵我国以来, 现已蔓延到我国 21 个省(市、自治区), 草地贪夜蛾将在我国定殖并呈现周年常态化发生态势, 对我国玉米产业的发展构成严重威胁。本文综述了草地贪夜蛾的国内外寄生性和捕食性天敌昆虫及其应用情况, 并就我国天敌昆虫产业发展的现状和存在的问题提出了建议, 以期应用天敌昆虫防控草地贪夜蛾提供参考。

关键词: 草地贪夜蛾; 生物防治; 寄生性天敌昆虫; 捕食性天敌昆虫

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Natural Enemy Insect Resources of the Fall Armyworm *Spodoptera frugiperda*, Their Application Status, and Existing Problems and Suggestions

CHEN Wanbin, LI Yuyan, WANG Mengqing, LIU Chenxi, MAO Jianjun, CHEN Hongyin, ZHANG Lisheng*

(Institute of Plant Protection, Chinese Academy of Agricultural Sciences/USDA-ARS Sino-American Biological Control Laboratory, Beijing 100193, China)

Abstract: Fall armyworm, *Spodoptera frugiperda* (Smith), is a major agricultural pest originating from the tropical and subtropical areas of the Americas. It is characterized by fast migration, broad host range, high reproductive capacity, strong damage ability, and wide adaptability. Nowadays, *S. frugiperda* has already spread to 21 provinces (city, municipality) in China since its invasion into China at the beginning of this year. It is seriously threatening the development of China's corn industry due to its establishment in China. In this paper, the parasitic and predatory natural enemy insects of *S. frugiperda* and their application status were summarized. Meanwhile, existing problems and advices for the development of natural enemy insects were suggested. The review is expected to serve as a reference for further studies.

Key words: *Spodoptera frugiperda*; biological control; parasitic natural enemy insect; predatory natural enemy insect

草地贪夜蛾 *Spodoptera frugiperda* (J. E. Smith) 是起源于美洲热带和亚热带地区的重要农业害虫, 俗称秋黏虫 (Fall armyworm, FAW)^[1]。其幼虫杂食性, 寄主植物多达 16 科 300 余种, 可取食为害玉米、水稻、大豆等农作物, 同时也是甘蔗、烟草等经济作物上的重要害虫^[2]。其成虫强大的跨境迁飞能力和增殖潜能是草地贪夜蛾在全球快速、大范围蔓延的主要因素之一^[3-5]。该虫于 2016 年 1 月在非洲被首次发现并报道^[6], 仅用两年时间就入侵到撒哈拉以南 44 个非洲国家^[7]。我国于 2019 年 1 月在云南江城首次发现草地贪夜蛾^[8], 目前, 该虫已在全国 21 个省 1246 个县蔓延发生, 实查发生面积 79.2 万 hm^2 , 草地贪夜蛾的入侵严重威胁和制约我国玉米产业的发展。据统计, 草地贪夜蛾在美国佛罗里

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作者简介: 陈万斌, 博士研究生, E-mail: chenwb24@126.com; *通信作者, 研究员, E-mail: zhangleesheng@163.com。

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达州导致玉米减产 20%^[5]。在经济落后或在病虫害控制资金缺乏的国家或地区,其损失更为严重,如在洪都拉斯^[9]、阿根廷^[10]等地其为害引起的玉米产量损失可高达 40%~72%。在我国,由于受季风等因素的影响,草地贪夜蛾已呈现出向黄淮海夏玉米产区和北方春玉米产区蔓延的态势,其发生和为害区域可能继续向东北方向延伸^[11],届时受威胁玉米面积预计在 1300 万 hm^2 以上,使我国玉米安全生产面临严重威胁^[12]。

关于草地贪夜蛾的防控技术主要有农业防治、生物防治、理化诱控、化学防治和监测技术^[12]。而生物防治作为 IPM 的重要组成部分,可以通过利用当地自然天敌资源以经济、环保的方式将害虫控制在经济损失允许水平之内。同样,生物防治还可通过减少非可再生资源石油衍生物的投入来促进作物管理系统的可持续性发展^[13]。我国是世界第二大玉米主产国,其玉米主产区的气候条件大都适宜草地贪夜蛾的发生与繁殖。相对较大的纬度跨度,使我国玉米等作物的布局呈现出从南到北递次推移的现象,作物的这种时间和空间上的布局特点为草地贪夜蛾提供了丰富的食料资源,草地贪夜蛾将会在我国定殖并呈现出周年常态化发生的态势^[12]。因此,对于草地贪夜蛾的防控应采取长期防控策略。鉴于此,为了在草地贪夜蛾的综合防治中更好地利用天敌昆虫资源对其进行长期防控,本文搜集和整理了草地贪夜蛾的天敌昆虫种类,并就其应用现状和当前我国在天敌昆虫产业方面存在的问题进行了综述,并提出了相应的建议,旨在为应用天敌昆虫防治草地贪夜蛾提供参考和依据。

1 草地贪夜蛾天敌昆虫资源

1.1 寄生性天敌昆虫

草地贪夜蛾有着丰富的寄生性天敌昆虫资源,本文整理出草地贪夜蛾的寄生性天敌共 206 种,主要以膜翅目 Hymenoptera (9 科)和双翅目 Diptera (4 科)为主,其中膜翅目占比 66.50%。包括茧蜂科 Braconidae 48 种、缘腹细蜂科 Scelionidae 2 种、赤眼蜂科 Trichogrammatidae 15 种、蜂虻科 Bombyliidae 1 种、蚤蝇科 Phoridae 2 种、麻蝇科 Sarcophagidae 6 种、寄蝇科 Tachinidae 60 种、肿腿蜂科 Bethyidae 1 种、小蜂科 Chalcididae 7 种、姬小蜂科 Eulophidae 14 种、姬蜂科 Ichneumonidae 47 种、巨胸小蜂科 Perilampidae 1 种、金小蜂科 Pteromalidae 2 种(表 1)。

1.2 捕食性天敌昆虫

草地贪夜蛾捕食性天敌昆虫也比较丰富,共 44 种,主要包括革翅目 Dermaptera 蠍蠍科 Forficulidae 6 种、肥蠍蠍科 Anisolabididae 1 种、鞘翅目 Coleoptera 瓢甲科 Coccinellidae 7 种、步甲科 Carabidae 5 种、半翅目 Hemiptera 猎蝽科 Reduviidae 5 种、长蝽科 Lygaeidae 2 种、花蝽科 Anthrenidae 2 种、姬蝽科 Nabidae 2 种、蝽科 Pentatomidae 7 种、脉翅目 Neuroptera 草蛉科 Chrysopidae 4 种,膜翅目 Hymenoptera 蚁科 Formicidae 2 种和胡蜂科 Vespidae 1 种。其中半翅目的蝽和鞘翅目的甲虫较多,占比 68.18%(表 2)。

2 天敌昆虫在草地贪夜蛾综合防治中的应用

由于我国的地理位置、农作物种植结构和布局特点以及气候等条件均适宜草地贪夜蛾的周年繁殖,因此草地贪夜蛾长期为害将成为事实,对其开展持续治理是我国当前以及未来相当长一段时间内所面临的重大植保任务。目前,化学防治仍是短期内控制草地贪夜蛾的主要方法^[106],在其原产地美洲部分地区,草地贪夜蛾已对有机磷酸酯类、氨基甲酸酯类等农药产生了抗性^[107]。相对于使用化学农药而言,天敌昆虫是自然界广泛存在的有益生物,能通过捕食或寄生的方式对害虫进行持续有效地控制。应用天敌昆虫能够在生产源头上避免或降低农产品的农药残留,对环境无污染,使害虫不易产生抗性。此外,天敌昆虫的应用是植物保护的重要组成部分,是农业病虫害绿色防控的重要措施,理应发挥重要作用。因此,害虫生物防治对保障农作物安全生产,维护生态系统平衡具有重要意义。

2.1 国外应用天敌昆虫防治草地贪夜蛾的情况

在寄生性天敌昆虫方面,对于夜蛾黑卵蜂的研究较为广泛。夜蛾黑卵蜂是亚洲和美洲地区许多鳞翅目农业害虫的重要卵寄生性天敌昆虫,尤其是对夜蛾科灰翅夜蛾属害虫,该寄生蜂已在拉丁美洲部分国家成功繁殖并释放。雌蜂会将卵产在正在发育的寄主胚胎内,在饲养过程中发现其存在过寄生现象,但由于子

表 1 草地贪夜蛾寄生性天敌名录
Table 1 List of parasitic natural enemy insects of fall armyworm

寄主 Host	目 Order	科 Family	种 Species	参考文献 Reference
卵 Egg	膜翅目 Hymenoptera	茧蜂科 Braconidae	奇痣窄径茧蜂 <i>Agathis stigmatera</i> (Cresson)	[14]
			<i>Chelonus antillarum</i> (Marshall)	[15]
			<i>Chelonus cautus</i> (Cresson)	[16]
			斜纹夜蛾甲腹茧蜂 <i>Chelonus formosanus</i> (Sonan)	[17]
			岛甲腹茧蜂 <i>Chelonus insularis</i> (Cresson)	[18]
			<i>Chelonus</i> sp.	[19]
		缘腹细蜂科 Scelionidae	夜蛾黑卵蜂 <i>Telenomus remus</i> (Nixon)	[20]
			<i>Telenomus</i> sp.	[15]
		赤眼蜂科 Trichogrammatidae	暖突赤眼蜂 <i>Trichogramma achaeae</i> (Nagaraja and Nagarkatti)	[17]
			长突赤眼蜂 <i>Trichogramma chilotraeae</i> (Nagaraja and Nagarkatti)	[17]
			螟黄赤眼蜂 <i>Trichogramma chilonis</i> (Ishii)	[21]
			<i>Trichogramma colombiense</i> (Velasquez de Rios and Teran)	[22]
			<i>Trichogramma demoraesi</i> (Zucchi)	[23]
			拟暗褐赤眼蜂 <i>Trichogramma exiguum</i> (Pinto and Platner)	[24]
			暗褐赤眼蜂 <i>Trichogramma fasciatum</i> (Perkins)	[25]
			<i>Trichogramma galloi</i> (Zucchi)	[26]
			阿根廷赤眼蜂 <i>Trichogramma koehleri</i> (Blanchard)	[22]
			微小赤眼蜂 <i>Trichogramma minutum</i> (Riley)	[27]
			短管赤眼蜂 <i>Trichogramma pretiosum</i> (Riley)	[28]
			智利赤眼蜂 <i>Trichogramma rojasi</i> (Nagaraja and Nagarkatti)	[29]
			<i>Trichogramma</i> sp. nr. <i>mwanzai</i> (Schulten et Feijen)	[30]
			<i>Trichogramma atopovirilia</i> (Oatman and Platner)	[28]
			<i>Trichogrammatoidea eldanae</i> (Viggiani)	[22]
幼虫 Larva	双翅目 Diptera	蜂虻科 Bombyliidae	壳乌蜂虻 <i>Poecilanthrax (Anthrax) lucifer</i> (Fabricius)	[15]
		蚤蝇科 Phoridae	<i>Megaselia scalaris</i> (Low)	[31]
			<i>Megaselia</i> sp.	[15]
		麻蝇科 Sarcophagidae	<i>Helicobia morionella</i> (Aldrich)	[15]
			<i>Rivinia assidua</i> (Walker)	[27]
			<i>Sarcodexia sternodontis</i> (Townsend)	[15]
			<i>Sarcophaga georgiana</i> (Weideman)	[15]
			闪烁麻蝇 <i>Sarcophaga lambens</i> (Weideman)	[32]
			<i>Sarcophaga</i> sp.	[15]
		寄蝇科 Tachinidae	<i>Acroglossa vetula</i> (Reinhard)	[33]
			<i>Admontia degeerioides</i> (Coquillett)	[27]
			广始寄蝇 <i>Archytas analis</i> (Fabricius)	[34]
			<i>Archytas apicifer</i> (Walker)	[15]
			<i>Archytas incasana</i> (Townsend)	[34]
			毛腹始寄蝇 <i>Archytas incertus</i> (Macquart)	[34]
			大理纹始寄蝇 <i>Archytas marmoratus</i> (Townsend)	[34]
			<i>Archytas plangens</i> (Curran)	[34]

续表 1

寄主 Host	目 Order	科 Family	种 Species	参考文献 Reference
			<i>Archytas</i> sp.	[15]
			<i>Chetogena</i> sp.	[15]
			<i>Cuphocerini</i> sp.	[15]
			荷甲寄蝇 <i>Eucelatoria armigera</i> (Coquillett)	[15]
			南方寄蝇 <i>Eucelatoria australis</i> (Townsend)	[15]
			<i>Eucelatoria bryani</i> (Sabrosky)	[15]
			<i>Eucelatoria guimaraesi</i>	[15]
			<i>Eucelatoria rubentis</i> (Coquillett)	[35]
			<i>Eucelatoria</i> sp.	[36]
			<i>Euphorocera floridensis</i> (Townsend)	[15]
			<i>Euphorocera</i> sp.	[15]
			大盆地天幕毛虫寄蝇 <i>Euphorocera tachinomoides</i> (Townsend)	[37]
			舞蛾追寄蝇 <i>Exorista mella</i> (Walker)	[37]
			<i>Gonia (Reaumuria) pacifica</i> (Townsend)	[38]
			阔额膝虹寄蝇 <i>Gonia capitata</i> (DeGeer)	[27]
			<i>Gonia crassicornis</i> (Fabricius)	[38]
			<i>Gonia</i> sp.	[15]
			<i>Gonia texensis</i> (Reinhard)	[15]
			<i>Hyphantrophaga collina</i> (Reinhard)	[15]
			美国白蛾寄蝇 <i>Hyphantrophaga hyphantriae</i> (Townsend)	[27]
			<i>Incamyia chilensis</i> (Aldrich)	[39]
			<i>Lespesia affinis</i> (Townsend)	[40]
			寡粘虫莱寄蝇 <i>Lespesia aletiae</i> (Riley)	[41]
			果树卷蛾莱寄蝇 <i>Lespesia archippivora</i> (Riley)	[34]
			<i>Lespesia frenchi</i> (Williston)	[27]
			<i>Lespesia grioti</i> (Blanchard)	[34]
			<i>Lespesia</i> sp.	[34]
			<i>Linnaemya annalis</i> (Townsend)	[15]
			饰蛾短须寄蝇 <i>Linnaemya comta</i> (Fallen)	[15]
			<i>Linnaemya</i> sp.	[42]
			螟利索寄蝇 <i>Lixophaga diatraeae</i> (Townsend)	[43]
			<i>Nemorilla pyste</i> (Walker)	[44]
			<i>Palexorista zonata</i>	[45]
			<i>Parasetigena</i> sp.	[38]
			<i>Patelloa similis</i> (Townsend)	[15]
			<i>Patelloa</i> sp.	[34]
			<i>Peleteria robusta</i> (Wiedeman)	[15]
			亮翅蜉寄蝇 <i>Phorocera claripennis</i> (Macquart)	[44]
			佛洛里达寄蝇 <i>Phorocera floridensis</i> (Townsend)	[15]
			<i>Pronemorilla mima</i> (Townsend)	[33]
			<i>Pseudokea</i> sp.	[15]

续表 1

寄主 Host	目 Order	科 Family	种 Species	参考文献 Reference
			<i>Tachinidae</i> sp.	[15]
			茹蝇寄蝇 <i>Voria ruralis</i> (Fallen)	[34]
			<i>Winthemia leucanae</i> (Kirkpatrick)	[15]
			<i>Winthemia mima</i> (Reinhard)	[34]
			红尾温寄蝇 <i>Winthemia quadripustulata</i> (Fabricius)	[15]
			<i>Winthemia reliqua</i>	[15]
			<i>Winthemia roblesi</i>	[15]
			<i>Winthemia rufopicta</i> (Bigot)	[44]
			<i>Winthemia sinuata</i> (Reinhard)	[37]
			<i>Winthemia</i> sp.	[34]
			温寄蝇 <i>Winthemia trinitatis</i> (Thompson)	[34]
膜翅目	Hymenoptera	肿腿蜂科 Bethyidae	<i>Perisierola</i> sp.	[46]
		茧蜂科 Braconidae	<i>Aleiodes caphimal</i>	[47]
			<i>Aleiodes</i> sp.	[34]
			<i>Aleiodes terminalis</i> (Cresson)	[15]
			<i>Aleiodes vauhani</i> (Muesebeck)	[48]
			脊茧蜂 <i>Alieodes laphygmae</i> (Viereck)	[49]
			<i>Bassus</i> sp.	[15]
			基氏茧蜂 <i>Bracon kirkpatricki</i> (Wilkinson)	[15]
			黑头折脉茧蜂 <i>Cardiochiles nigriceps</i> (Viereck)	[50]
			网螟甲腹茧蜂 <i>Chelonus texanus</i> (Cresson)	[51]
			<i>Cotesia icipe</i> (Fernandez-Triana and Fiaboe)	[52]
			<i>Distatrix</i> sp.	[15]
			<i>Dolichozele koebelei</i> (Viereck)	[53]
			<i>Exasticolus fuscicornis</i> (Cameron)	[54]
			绒茧蜂 <i>Glyptapanteles creatonoti</i> (Viereck)	[55]
			<i>Glyptapanteles militaris</i> (Walsh)	[31]
			<i>Gnathopleura</i> sp.	[15]
			麦蛾柔茧蜂 <i>Habrobracon hebetor</i> (Say)	[56]
			截距滑茧蜂 <i>Homolobus truncator</i> (Say)	[15]
			<i>Macrocentrus</i> sp.	[36]
			<i>Meteorus arizonensis</i> (Muesebeck)	[57]
			甘兰金斑蛾悬茧蜂 <i>Meteorus autographae</i> (Muesebeck)	[58]
			悬茧蜂 <i>Meteorus laphygmae</i> (Viereck)	[59]
			<i>Meteorus</i> sp.	[15]
			普通悬茧蜂 <i>Meteorus vulgaris</i> (Cresson)	[27]
			藏红足侧沟茧蜂 <i>Microplitis croceipes</i> (Cresson)	[60]
			马尼拉侧沟茧蜂 <i>Microplitis manilae</i> (Ashmead)	[61]
			红腹侧沟茧蜂 <i>Microplitis rufiventris</i> (Kokujev)	[62]
			斯氏侧沟茧蜂 <i>Microplitis similis</i> (Lyle)	[63]
			<i>Microplitis</i> sp.	[15]

续表 1

寄主 Host	目 Order	科 Family	种 Species	参考文献 Reference
			<i>Palinzele</i> sp.	[17]
			灰灯蛾原绒茧蜂 <i>Protapanteles creatonoti</i> (Viereck)	[22]
			甜菜贪夜蛾内茧蜂 <i>Rogas laphygmae</i> (Viereck)	[31]
			内茧蜂 <i>Rogas vaughani</i> (Muesebeck)	[31]
			<i>Stantonia</i> sp.	[15]
		小蜂科 Chalcididae	<i>Conura</i> (<i>Ceratosmicra</i>) <i>hirtifemora</i> (Ashmead)	[64]
			<i>Conura</i> (<i>Ceratosmicra</i>) <i>immaculata</i> (Cresson)	[15]
			美国白蛾小角小蜂 <i>Conura</i> (<i>Ceratosmicra</i>) <i>meteor</i> (Burks)	[65]
			大腿斑小蜂 <i>Conura</i> (<i>Spilochalcis</i>) <i>femorata</i> (Fabricius)	[15]
			<i>Conura igneoides</i> (Kirby)	[15]
		姬小蜂科 Eulophidae	长尾啮小蜂属 <i>Aprostocetus</i> sp.	[66]
			棉铃虫裹尸薄茧小蜂 <i>Euplectrus comstocki</i> (Howard)	[67]
			<i>Euplectrus furnicus</i> (Walker)	[34]
			<i>Euplectrus hircinus</i> (Say)	[47]
			<i>Euplectrus insularis</i> (Howard)	[48]
			<i>Euplectrus marginatus</i> (Ashmead)	[15]
			长距姬小蜂 <i>Euplectrus platyhypenae</i> (Howard)	[68]
			<i>Euplectrus ronnai</i> (Brethes)	[15]
			<i>Euplectrus</i> sp.	[15]
			<i>Horismenus</i> sp.	[66]
			<i>Trichodischia caerulea</i> (Bigot)	[38]
			突额姬小蜂 <i>Trichospilus diatraeae</i> (Cherian and Margabandhu)	[69]
			<i>Trichospilus</i> sp.	[15]
		姬蜂科 Ichneumonidae	<i>Amblyteles</i> sp.	[15]
			<i>Ancyloneura</i> sp.	[15]
			<i>Anomalon ejuncidum</i> (Say)	[58]
			棉铃虫齿唇姬蜂 <i>Campoletis chloridae</i> (Uchida)	[55]
			<i>Campoletis curvicauda</i> (Blanchard)	[15]
			黄带齿唇姬蜂 <i>Campoletis flavicincta</i> (Ashmead)	[49]
			<i>Campoletis grioti</i> (Blanchard)	[34]
			<i>Campoletis oxylus</i> (Cresson)	[15]
			黑唇姬蜂 <i>Campoletis sonorensis</i> (Cresson)	[49]
			<i>Campoletis</i> sp.	[15]
			<i>Campoplex</i> sp.	[15]
			<i>Charops ater</i> (Szépligeti)	[45]
			<i>Diadegma</i> sp.	[34]
			环纹茧蜂 <i>Eiphosoma annulatum</i> (Cresson)	[33]
			<i>Eiphosoma laphygmae</i> (Costa Lima)	[70]
			<i>Eiphosoma</i> sp.	[15]
			<i>Eiphosoma vitticoll</i> (Cresson)	[71]
			<i>Enicospilus flavus</i> (Fabricius)	[15]

续表 1

寄主 Host	目 Order	科 Family	种 Species	参考文献 Reference			
			细顎姬蜂 <i>Enicospilus merdarius</i> (Gravenhorst)	[22]			
			<i>Goryphina</i> sp.	[15]			
			<i>Hyposoter annulipes</i> (Cresson)	[72]			
			<i>Hyposoter</i> sp.	[15]			
			<i>Isdromas lycaenae</i> (Howard)	[64]			
			盘背菱室姬蜂 <i>Mesochorus disceitergus</i> (Say)	[64, 65]			
			<i>Microcharops anticarsiae</i> (Gupta)	[48]			
			<i>Neotheronia</i> sp.	[31]			
			塞氏拟瘦姬蜂 <i>Netelia sayi</i> (Cushman)	[50]			
			<i>Netelia</i> sp.	[73]			
			<i>Ophion ancyloneura</i> (Wichsee)	[34]			
			<i>Ophion bilineatus</i> (Say)	[27]			
			<i>Ophion flavidus</i> (Brulle)	[34]			
			<i>Ophion merdarius</i> (Gravenhorst)	[15]			
			瘦姬蜂 <i>Ophion</i> sp.	[15]			
			<i>Parania (Atrometus) tricolor</i> (Morley)	[15]			
			红足黑瘤姬蜂 <i>Pimpla rufipes</i> (Miller)	[22]			
			<i>Pristomerus</i> sp.	[31]			
			具刺齿腿姬蜂 <i>Pristomerus spinator</i> (Fabricius)	[74]			
			<i>Sagaritis dubitatus</i> (Cresson)	[27]			
			<i>Temelucha difficilis</i> (Dasch.)	[58]			
			<i>Temelucha grapholithae</i> (Cushman)	[75]			
			<i>Temelucha</i> sp.	[48]			
			<i>Trachysphyrus cleonis</i> (Viereck)	[73]			
			巨胸小蜂科 Perilampidae	蠋姬蜂巨胸小蜂 <i>Perilampus hyalinus</i> (Say)	[15]		
			金小蜂科 Pteromalidae	<i>Catalaccus aeneoviridis</i> (Girault)	[65]		
				<i>Trichomalopsis viridescens</i> (Walsh)	[64, 65]		
			蛹 Pupa	膜翅目 Hymenoptera	小蜂科 Chalcididae	<i>Brachymeria ovata</i> (Say)	[34]
						<i>Brachymeria robusta</i> (Cresson)	[15]
					姬小蜂科 Eulophidae	<i>Trichospilus pupivora</i> (Ferriere)	[36]
姬蜂科 Ichneumonidae	<i>Cryptus albitarsis</i> (Cresson)	[76]					
	<i>Diapetimorpha introita</i> (Cresson)	[77]					
	<i>Ichneumon ambulatorius</i> (Fabricius)	[15]					
	<i>Ichneumon promissorius</i> (Cresson)	[15]					
	<i>Vulgichneumon brevicintor</i> (Say)	[76]					
	曲斑甲腹茧蜂 <i>Chelonus curvimaculatus</i> (Cameron)	[56]					
	<i>Chelonus maudae</i> (Huddleston)	[56]					
	<i>Coccygidium luteum</i> (Brullé)	[45]					
	甘蓝夜蛾绒茧蜂 <i>Cotesia (Apanteles) congregata</i> (Say)	[72]					
	<i>Cotesia (Apanteles)</i> sp.	[36]					
	菜粉蝶盘绒茧蜂 <i>Cotesia glomerata</i> (Linnaeus)	[36]					
缘腹绒茧蜂 <i>Cotesia marginiventris</i> (Cresson)	[48]						
螟蛉盘绒茧蜂 <i>Cotesia ruficrus</i> (Haliday)	[17]						

表 2 草地贪夜蛾的捕食性天敌名录

Table 2 List of predatory natural enemy insect of fall armyworm

目 Order	科 Family	种 Species	参考文献 Reference
革翅目 Dermaptera	蠹螋科 Forficulidae	<i>Diaperasticus erythrocephalus</i> (Olivier)	[56]
		<i>Doru lineare</i> (Eschscholtz)	[78]
		<i>Doru luteipes</i> (Scudder)	[79]
		<i>Doru taeniatum</i> (Dorhn)	[9]
		<i>Forficula</i> sp.	[55]
		<i>Labidura riparia</i> (Pallias)	[80]
鞘翅目 Coleoptera	肥螋螋 Anisolabididae	<i>Euborellia annulipes</i> (Lucas)	[81]
	瓢甲科 Coccinellidae	大斑长足瓢虫 <i>Coleomegilla maculata</i> (De Geer)	[82]
		血红环瓢虫 <i>Cycloneda sanguinea</i> (L.)	[56]
		<i>Eriopis connexa</i> (Mulsant)	[56]
		异色瓢虫 <i>Harmonia axyridis</i> (Pallas)	[56]
		集栖瓢虫 <i>Hippodamia convergens</i> (Guérin-Méneville)	[56]
		<i>Neda conjugata</i> (Mulsant)	[56]
		楔斑溜瓢虫 <i>Olla v-nigrum</i> (Mulsant)	[56]
	步甲科 Carabidae	<i>Calleida decora</i> (Fabricius)	[83]
		<i>Calosoma alternans granulatum</i> (Perty)	[84]
		<i>Calosoma granulatum</i> (Perty)	[56]
		<i>Calosoma sayi</i> (Fabricius)	[85]
		<i>Megacephala carolina carolina</i> (L.)	[86]
半翅目 Hemiptera	猎蝽科 Reduviidae	<i>Sycanus indagator</i> (Stål)	[87]
		黑斑择猎蝽 <i>Zelus armillatus</i> (Lepeletier and Serville)	[56]
		长角择猎蝽 <i>Zelus leucogrammus</i> (Perty)	[56]
		长足择猎蝽 <i>Zelus longipes</i> (L.)	[88]
		任氏择猎蝽 <i>Zelus renardii</i> (Kolenati)	[89]
	长蝽科 Lygaeidae	斑足大眼长蝽 <i>Geocoris punctipes</i> (Say)	[90]
		沼泽大眼长蝽 <i>Geocoris uliginosus</i> (Say)	[90]
	花蝽科 Anthocoridae	狡诈小花蝽 <i>Orius insidiosus</i> (Say)	[90]
		东亚小花蝽 <i>Orius sauteri</i> (Poppius)	[91]
	姬蝽科 Nabidae	<i>Nabis capsiformis</i> (Germar)	[92]
		<i>Nabis rugosus</i> (L.)	[56]
	蝽科 Pentatomidae	蝽蝽 <i>Arma chinensis</i> (Fallou)	[93]
		佛州优捕蝽 <i>Euthyrhynchus floridanus</i> (L.)	[94]
		益蝽 <i>Picromerus lewisi</i> (Scott)	[95]
		<i>Podisus connexivus</i> (Bergroth)	[96]
		斑腹刺肩蝽 <i>Podisus maculiventris</i> (Say)	[97]
		黑刺益蝽 <i>Podisus nigrispinus</i> (Dallas)	[98]
		<i>Supputius cincticeps</i> (Stål)	[99]
脉翅目 Neuroptera	草蛉科 Chrysopidae	<i>Ceraeochrysa cubana</i> (Hagen)	[100]
		大草蛉 <i>Chrysopa pallens</i> (Rambur)	[101]
		普通草蛉 <i>Chrysoperla carnea</i> (Stephens)	[102]
		<i>Chrysoperla externa</i> (Hagen)	[103]
膜翅目 Hymenoptera	蚁科 Formicidae	<i>Ectatomma ruidum</i> (Roger)	[104]
		红火蚁 <i>Solenopsis invicta</i> (Buren)	[76]
	胡蜂科 Vespidae	<i>Stelopolybia pallipes</i> (Oliver)	[105]

代个体之间的互相竞争及寄主卵营养有限使得只有一个个体能成功发育。雌蜂在羽化后前5 d的产卵量占总产卵量的76%以上。夜蛾黑卵蜂第一次被用于生物防治是该蜂在1963年从巴布新几内亚引入印度时,之后又被引入到亚洲国家^[108]。在委内瑞拉,每次以5000头的放蜂量在3周内连续释放3次夜蛾黑卵蜂对草地贪夜蛾进行防控。释放两个月后调查发现,在距离放蜂点30~1400 m的范围内草地贪夜蛾的被寄生率为78%~100%,在距离放蜂点2000~2200 m区域的寄生率为60%~83%。选择适宜的放蜂点和最佳的放蜂量有助于达到更好的控害效果^[109]。1991—1994年在洪都拉斯玉米田和高粱田释放夜蛾黑卵蜂后调查发现,不同月份之间的寄生率在20%~92%波动。每周以75000~105000头/hm²的量放蜂后的寄生率相对较高,而释放35000~50000头/hm²后的寄生率较低。夜蛾黑卵蜂目前在多个拉丁美洲国家被大规模饲养用于商业用途或科学研究,委内瑞拉和哥伦比亚的私人公司也在生产并出售^[108]。

Figueiredo等^[110]在巴西有机玉米田释放短管赤眼蜂后调查发现,有79.2%的草地贪夜蛾卵块被寄生,与对照相比,放蜂区的玉米产量增加了701 kg/hm²。相当于每公顷增产19.4%和增收96.5美元。在调查中还发现捕食性天敌*Doru luteipes*、*Orius* sp.和Coccinellids对草地贪夜蛾幼虫和卵的捕食率分别为21.57%、1.22%和0.5%。Neto等^{[111][120]}2001年在玉米田释放不同密度的黄带齿唇姬蜂后草地贪夜蛾幼虫数量均有所降低,但草地贪夜蛾的死亡率和寄生蜂的雌性比在各处理间不存在显著差异。相对于对照区而言,释放15对和30对寄生蜂后,玉米可分别增产15.44%和11.59%。除此之外,美洲国家在草地贪夜蛾防控中所用的寄生蜂还有岛甲腹茧蜂、缘腹绒茧蜂、长距姬小蜂、网螟甲腹茧蜂、*Aleiodes laphygmae*(Viereck)、*Campoletis sonorensis*(Cameron)以及寄生蝇*Lespesia archippivora*(Riley)和*Archytas incertus*(Macquart)等^[9, 31, 51]。

自草地贪夜蛾入侵非洲以来,当地数以百万计人口的粮食安全面临严重威胁并使农民蒙受重大经济损失。据国际农业和生物科学中心(CABI)在非洲12个玉米生产国进行的调查表明,如果不加以控制,草地贪夜蛾每年对当地玉米生产可造成830万t至2060万t的损失。因此,为了草地贪夜蛾IPM的发展,对当地自然天敌的调查研究是至关重要的^[112]。在坦桑尼亚、埃塞俄比亚和肯尼亚的调查中发现5种从未在非洲和美洲报道的卵和幼虫寄生性天敌,分别是4种膜翅目*Cotesia icipe*、*Charops ater*、*Coccygidium luteum*、*Chelonus curvimaculatus*寄生蜂和1种双翅目*Palexorista zonata*寄生性天敌。在肯尼亚和坦桑尼亚,*Charops ater*和*Coccygidium luteum*是较为常见的,其寄生率分别为6%~12%和4%~8.3%。而*Cotesia icipe*是埃塞俄比亚的优势种,寄生率为33.8%~45.3%^[45]。Shylesha等^[55]在印度卡纳塔克邦的调查中发现*Telenomus* sp.和*Trichogramma* sp.两种卵寄生蜂,*Glyptapanteles creatonoti*(Viereck)和*Campoletis chloridae*(Uchida)两种幼虫寄生蜂以及1种幼虫-蛹寄生蜂。其中,草地贪夜蛾是在全球记录的*G. creatonoti*的第一个寄主,该寄生蜂可在印度和马来西亚寄生各种夜蛾科害虫并对草地贪夜蛾有很好的寄生潜能。

捕食性天敌昆虫在害虫生物防治中也同样发挥着重要作用。研究发现,*Doru luteipes*平均每雌产卵26.6粒,若虫和成虫分别每天可捕食草地贪夜蛾幼虫12和21头。田间药效试验表明,对草地贪夜蛾有毒杀作用的化学药剂二氯苯醚菊酯、溴氰菊酯等对*Doru luteipes*没有明显的影响。由此可看出,*Doru luteipes*对草地贪夜蛾有很好的控制效果^[79]。在天敌昆虫的实际应用中寻找一种对靶标寄主捕食率高且取食靶标害虫后发育状况良好的捕食性天敌昆虫是正确选择天敌并将其纳入害虫综合治理方案的重要步骤之一。*Cereaochrysa cubana*幼虫在取食草地贪夜蛾卵后的发育历期比取食幼虫后更短。可能是因为草地贪夜蛾卵内充足的营养物质是*Cereaochrysa cubana*获得较高化蛹率的重要条件^[100]。

2.2 目前国内在应用天敌昆虫防控草地贪夜蛾方面的研究进展

在我国,由中国农业科学院植物保护研究所天敌昆虫研究组率先开展了应用天敌昆虫防控草地贪夜蛾方面的研究工作。室内试验表明,蠋蝽5龄若虫每日最多可捕食6龄草地贪夜蛾幼虫3.175头。通过对其捕食行为的观察发现,蠋蝽可在草地贪夜蛾的头、胸、腹部各节处向猎物体内刺入其口针。在口针刺入猎物体内后,蠋蝽会随猎物的挣脱随其移动以保持口针始终处于刺入猎物体内的状态。在猎物失去活力后,蠋蝽会持续吮吸猎物体液直至草地贪夜蛾虫体干瘪后才收回口针,然后继续寻找新的猎物^[93]。同时,本实验室也研究了蠋蝽对不同龄期草地贪夜蛾幼虫的捕食能力。结果表明,蠋蝽对草地贪夜蛾3、4、5龄幼虫的日最大捕食量分别约为59、23和9头^[113]。本实验室在益蝽对草地贪夜蛾捕食功能反应的研究中发现,益蝽5龄若虫每日最多可捕食草地贪夜蛾6龄幼虫4.671头。但其在捕食行为方面与蠋蝽存在差异,当猎

物密度较低时益蝽会将猎物体躯吮吸干瘪,然后再寻找新猎物;而猎物密度较高时,益蝽将猎物制服后不会持续吮吸体液而是继续攻击下一头猎物,可在短时间内杀死大量猎物。这一特点对于控制繁殖力较强的草地贪夜蛾种群十分有利^[95]。此外,通过在云南安宁、寻甸、墨黑、勐海等地的田间试验发现,蝽蝽和益蝽均可在9 min内发现并锁定害虫,在距离猎物1 cm时会迅速发起攻击,将口针刺入草地贪夜蛾体内吮吸寄主体液,并分泌麻醉剂导致其麻痹,最终草地贪夜蛾因体液营养丧失、体内组织器官损坏而死亡^[114]。国内其他单位也研究了大草蛉^[101]、东亚小花蝽^[91]和异色瓢虫^[115]等其他捕食性天敌昆虫对草地贪夜蛾的控制效果。

我国科研人员在草地贪夜蛾寄生性天敌昆虫方面也做了相关研究并取得一定成果。在香港和广东地区草地贪夜蛾天敌资源的调查中发现螟黄赤眼蜂和夜蛾黑卵蜂两种卵寄生蜂,且在调查中还发现这两种寄生蜂可在同一卵块上寄生。因此,在后续的防治工作中将两种寄生蜂混合释放将会成为可能^[21]。茧蜂科的斯氏侧沟茧蜂能寄生草地贪夜蛾2~4龄幼虫,可以显著抑制其取食和体重增长,能有效的阻滞幼虫进入暴食期最终使其死亡^[63]。吉林农业大学生物防治研究所从赞比亚采集并鉴定出3种草地贪夜蛾卵寄生蜂,分别为赤眼蜂 *Trichogramma* sp. nr. *mwanzai* Schulten et Feijen、夜蛾黑卵蜂和甲腹茧蜂 *Chelonus* sp.。在室内繁育时发现赤眼蜂可在中间寄主米蛾 *Corcyra cephalonica* (Stainton) 卵上成功寄生,而其他两种蜂可在斜纹夜蛾 *Spodoptera litura* (Fabricius) 卵和甜菜夜蛾 *Spodoptera exigua* (Hübner) 卵上寄生。该研究为下一步建立草地贪夜蛾优势蜂种和工厂化繁育天敌昆虫提供了参考和依据,并为推广天敌昆虫生物防治草地贪夜蛾奠定了基础^[30]。

3 我国在天敌昆虫应用方面存在的问题

草地贪夜蛾疫情发生后,农业农村部、全国农业技术推广服务中心研究并确定了以“长短结合、标本兼治”为原则、生态控制和农业防治为基础、生物防治和理化诱控为重点,化学防治为底线的草地贪夜蛾防控对策。从当前国内外对草地贪夜蛾生物防治的科研进展与应用实践方面来看,通过天敌昆虫“以虫治虫”是控制草地贪夜蛾是有效可行的防控措施。但相对于发达国家,我国天敌昆虫产业的发展面临一定的困难,具体如下:

(1) 政府对天敌昆虫产业的扶持力度和重视程度较低

尽管近年来我国在积极推进农作物病虫害专业化统防统治,且中央和地方财政也投入了大量资金,但相当一部分资金都用于化学农药和用药机械的采购或补贴,而用于天敌昆虫产品采购或补贴方面的资金却寥寥无几。其次,国家和各级农业技术推广部门对天敌昆虫产业方面的倡导、宣传、培训、示范和推广力度不足,以至于在基层频频出现无人知晓天敌昆虫的尴尬局面。

(2) 我国天敌昆虫产业的研发、生产和服务能力薄弱

我国农业化工产业经过近几十年的发展已逐步建立了相对完善的农药化工体系,已登记在册的农药生产企业多达数千家,农药生产成本普遍大幅下降。相对于发展日趋繁荣和成熟的农业化工产业而言,天敌昆虫产业的发展就显得微不足道。目前,我国仅有为数不多的十余家天敌生产企业,且大部分都依附或脱胎于科研单位,资金投入不足,技术力量薄弱,缺乏规模化的流水线生产车间,从业人员数量少,以至于不能大批量稳定生产,在急需天敌昆虫产品的时候无法及时供货,远不能满足实际生产的需求。再加上机械化和自动化程度较低导致部分天敌昆虫产品生产成本较高,销售价格高于化学农药,致使农民不能接受。

(3) 天敌昆虫产品人工繁育的关键技术缺失

天敌昆虫产品本身的特殊性使得其对人工扩繁的技术要求较高。天敌昆虫产品是活体生物,相对于化学农药而言,其生产周期长,货架期较短。一般情况下,用户在收到天敌昆虫产品后须在短时间内马上使用,因此天敌昆虫生产企业就不可能像农化企业一样大批量生产或储存产品,而需要订单式生产。天敌昆虫产品除了对生产人员有较高的技术要求之外,用户在使用的时候也需要掌握一定的技术。特别是在使用时要掌握好天敌昆虫的投放时间、地点、数量以及投放的方法或技术等。因此人工扩繁、贮存及释放等方面关键技术的缺失是天敌昆虫产业发展的另一瓶颈。

(4) 基层对天敌昆虫产品的认知度和应用技术缺乏

基层农技推广部门工作人员对天敌昆虫产品的了解不够系统、对使用技术不够熟练以至于不能正确指导农户应用天敌产品防治植物虫害,而是习惯于使用化学农药。基层的推广力度不够,我国广大农民朋友没有得到关于生物防治方面的系统培训,普遍缺乏对生防的原理、技术、优点以及成本等的系统了解。再加上我国以家庭为单位的作物种植模式不利于大规模生物防治的实施也是限制其发展的一个因素。

4 我国天敌昆虫产业发展的相关建议

针对现阶段我国天敌昆虫应用方面存在的问题,结合国外生防技术较发达国家的经验和我国的现状,对我国天敌昆虫产业的发展提出以下建议:

首先,建议政府把天敌昆虫产品纳入统防统治范畴,增加天敌昆虫产品的比重,并逐渐加大采购力度。有关部门出台相关政策鼓励和引导天敌企业的发展,在财政资金方面应予以倾斜或支持。对于以家庭为单位自发购买使用天敌昆虫产品的用户,政府应制定相应的财政补贴政策,把天敌昆虫产品纳入农资补贴范畴,加大补贴比例,降低用户购买成本,从政策上引导种植户主动选择天敌昆虫产品,使天敌昆虫产品在害虫综合治理中的使用越来越普遍化。

其次,针对天敌昆虫产业存在的核心和关键技术瓶颈,充分发挥科企合作优势,让优势科研单位与企业大力合作、深度介入,推动科研院所与企业共建研发中心、集成示范基地等。进一步优化和完善天敌昆虫产品的繁育、贮存和使用技术,寻找最佳的投放密度、时间以及方法技术等使天敌昆虫产品控害效果最大化。促进天敌昆虫繁育与应用核心技术集成创新,提升我国天敌昆虫产业的核心竞争力。

最后,各级农业技术推广部门和相关工作人员要加大对天敌昆虫技术和产品的宣传力度,把生物防治技术纳入到培训的内容当中,通过现场示范或观摩等手段让农户以“看得见、摸得着”的方式亲身体会到天敌昆虫产品的优点,提升广大农民朋友对天敌昆虫产品的认知能力,转变对农作物病虫害治理方式的选择,使天敌昆虫成为绿色防控的关键技术支撑。真正促进天敌昆虫产业的振兴与发展,使天敌资源在我国病虫害防治中发挥重要作用,实现农作物病虫害的无害化治理和长久可持续发展。

参 考 文 献

- [1] Todd E L, Poole R W. Keys and illustrations for the armyworm moths of the noctuid genus *Spodoptera* Guenée from the Western Hemisphere[J]. Annals of the Entomological Society of America, 1980, 73(6): 722-738.
- [2] 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.
- [3] Deshmukh S, Kalleshwaraswamy C M, Asokan R, et al. First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India[J]. Pest Management in Horticultural Ecosystems, 2018, 24(1): 23-29.
- [4] 郭井菲, 何康来, 王振营. 草地贪夜蛾的生物学特性、发展趋势及防控对策[J]. 应用昆虫学报, 2019, 56(3): 361-369.
- [5] Early R, Gonzalez-Moreno P, Murphy S T, et al. Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm[J]. NeoBiota, 2018, 40: 25-50.
- [6] Goergen G, Kumar P L, Sankung S B, et al. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in west and central Africa[J]. PLoS ONE, 2016, 11(10): e165632.
- [7] Feldmann F, Rieckmann U, Winter S. The spread of the fall armyworm *Spodoptera frugiperda* in Africa—What should be done next?[J]. Journal of Plant Diseases and Protection, 2019, 126(2): 97-101.
- [8] 全国农业技术推广服务中心. 植物病虫害情报(第7期). 重大害虫草地贪夜蛾已侵入云南各地要立即开展调查监测[R]. 2019. https://www.natesc.org.cn/Html/2019_01_29/28092_151760_2019_01_29_457209.html.
- [9] Wyckhuys K A G, O'Neil R J. Population dynamics of *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) and associated arthropod natural enemies in Honduran subsistence maize[J]. Crop Protection, 2006, 25(11): 1180-1190.
- [10] Gabriela M, Molina-Ochoa J, Coviella C. Population dynamics of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and its parasitoids in northwestern Argentina[J]. Florida Entomologist, 2006, 89(2): 175-182.
- [11] 吴秋琳, 姜玉英, 胡高, 等. 中国热带和南亚热带地区草地贪夜蛾春夏两季迁飞轨迹的分析[J]. 植物保护, 2019, 45(3): 1-9.

- [12] 杨普云, 朱晓明, 郭井菲, 等. 我国草地贪夜蛾的防控对策与建议[J]. 植物保护, 2019, 45(4): 1-6.
- [13] Quimby P C, King L R, Grey W E. Biological control as a means of enhancing the sustainability of crop/land management systems[J]. Agriculture Ecosystems & Environment, 2002, 88(2): 147-152.
- [14] Simmonds F J. Insect pests of sugar-cane in the French Antilles[J]. Tropical Agriculture, 1953, 30(4-6): 122-127.
- [15] Molina-Ochoa J, Carpenter J E, Heinrichs E A, et al. Parasitoids and parasites of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas and Caribbean Basin: An inventory[J]. Florida Entomologist, 2003, 86(3): 254-289.
- [16] Molina-Ochoa J, Hamm J J, Lezama-Gutierrez R, et al. A survey of fall armyworm (Lepidoptera: Noctuidae) parasitoids in the Mexican states of Michoacán, Colima, Jalisco, and Tamaulipas[J]. Florida Entomologist, 2001, 84(1): 31-36.
- [17] Yaseen M. Introduction of exotic parasites for control of *Spodoptera* and *Heliothis* in Trinidad[J]. Proceedings of the Caribbean Food Crops Society, 1979, 15: 136-141.
- [18] Rezende M A A, Cruz I, Della Lucia T M C. Biological aspects of the parasitoid *Chelonus insularis* (Cresson) (Hymenoptera, Braconidae) reared on eggs of *Spodoptera frugiperda* (Smith) (Lepidoptera, Noctuidae)[J]. Revista Brasileira de Zoologia, 1995, 12(4): 779-784.
- [19] Valicente F H, Barreto M R. Survey of natural enemies of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), in the Cascavel region, PR, Brazil[J]. Anais da Sociedade Entomologica do Brasil, 1999, 28(2): 333-337.
- [20] Pomari A F, Bueno A F, Bueno R C O F, et al. *Telenomus remus* Nixon egg parasitization of three species of *Spodoptera* under different temperatures[J]. Neotropical Entomology, 2013, 42(4): 399-406.
- [21] 李志刚, 吕欣, 押玉柯, 等. 粤港两地田间发现夜蛾黑卵蜂与螟黄赤眼蜂寄生草地贪夜蛾[J]. 环境昆虫学报, 2019, 41(4): 760-765.
- [22] 唐璞, 王知知, 吴琼, 等. 草地贪夜蛾的天敌资源及其生物防治中的应用[J]. 应用昆虫学报, 2019, 56(3): 370-381.
- [23] Pratisoli D, Torres J B, Zanuncio J C. Selectivity of *Trichogramma demoraesi* (Hymenoptera: Trichogrammatidae) in infertile eggs of three lepidopterans[J]. Agro-Ciencia, 1999, 15(1): 75-80.
- [24] Diaz M F, Ramirez A, Poveda K. Efficiency of different egg parasitoids and increased floral diversity for the biological control of noctuid pests[J]. Biological Control, 2012, 60(2): 182-191.
- [25] Young J R, Ham J J. Reproduction of *Trichogramma fasciatum* in eggs from tepa-sterilized fall armyworms[J]. Journal of Economic Entomology, 1967, 60(3): 723-724.
- [26] Consoli F L, Kitajima E W, Parra J R P. Ultrastructure of the natural and factitious host eggs of *Trichogramma galloi* Zucchi and *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae)[J]. International Journal of Insect Morphology & Embryology, 1999, 28(3): 211-231.
- [27] Luginbill P. The fall armyworm[M]. Washington, DC: USDA Technical Bulletin, 1928.
- [28] Dequech S T B, Camera C, Sturza V S, et al. Population fluctuation of *Spodoptera frugiperda* eggs and natural parasitism by *Trichogramma* in maize[J]. Acta Scientiarum-agronomy, 2013, 35(3): 295-300.
- [29] Camera C, Dequech S T B, Ribeiro L P, et al. First report of *Trichogramma rojasi* parasitizing eggs of *Spodoptera frugiperda*[J]. Ciencia Rural, 2010, 40(8): 1828-1830.
- [30] 戴鹏, 孙佳伟, 陈永明, 等. 赞比亚发现三种防治草地贪夜蛾的卵寄生蜂简报[J]. 吉林农业大学学报, 2019, DOI: 10.13327/j.jjlau.2019.5310.
- [31] Ruíz-Nájera R E, Molina O J, Carpenter J E, et al. Survey for Hymenopteran and Dipteran parasitoids of the fall armyworm (Lepidoptera: Noctuidae) in Chiapas, México[J]. Journal of Agricultural and Urban Entomology, 2007, 24(1): 35-42.
- [32] Fennah R G. Insect pests of food crops in the Lesser Antilles[M]. Grenada: Department of Agriculture, 1947.
- [33] Notz P A. Parasitism by Diptera and Hymenoptera of larvae of *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) collected on maize, Maracay, Venezuela[J]. Revista de la Facultad de Agronomía de la Universidad Central de Venezuela, 1972, 6(3): 5-16.
- [34] Virla E G, Colomo M V, Berta C, et al. The complex of parasitoids of fall armyworm of maize, *Spodoptera frugiperda*, in Argentina (Insecta: Lepidoptera)[J]. Neotrópica, 1999, 45(113): 3-12.
- [35] Ashley T R, Mitchell E R, Leppla N C, et al. Parasites attacking fall armyworm larvae, *Spodoptera frugiperda*, in late planted field corn[J]. Florida Entomologist, 1980, 63(1): 136-142.
- [36] Alam M M. Attempts at the biological control of major insect pests of maize in Barbados, W. I.[C]. Joint symposium on maize and peanut. Paramaribo,

- Suriname, Proceedings of the Caribbean Food Crops Society, 1979, 127-135.
- [37] Wall R, Berberet R C. Parasitoids associated with lepidopterous pests on peanuts; Oklahoma fauna[J]. Environmental Entomology, 1975, 4(6): 877-882.
- [38] Guimaraes J H. Host-parasite and parasite-host catalogue of south American Tachinidae (Diptera)[J]. Arquivos de Zoologia, 1977, 28(3): 1-131.
- [39] Murua M G, Molina-Ochoa J, Fidalgo P. Natural distribution of parasitoids of larvae of the fall armyworm, *Spodoptera frugiperda*, in Argentina[J]. Journal of Insect Science (Madison), 2009, 9(20): 1-16.
- [40] Guimaraes J H. Taxonomy of brazilian flies of the genus *lespesia* robineau-desvoidy (diptera, tachinidae)[J]. Papeis avulsos de zoologia, 1983, 35(2): 11-30.
- [41] Gonzalez-Maldonado M B, Hernandez-Zetina D A, Ruiz-Cancino E. Parasitoids (Diptera: Tachinidae) of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) in maize in Durango, Mexico[J]. Southwestern Entomologist, 2018, 43(1): 183-187.
- [42] Benzing A, Kleespies R G, Ponce F. Natural mortality of noctuid larvae (Lepidoptera) in the Ecuadorian andes: a first approximation[J]. Revista Colombiana De Entomología, 2000, 26(1): 57-60.
- [43] Mcpherson R M, Hensley S D. Development of *Lixophaga diatraeae* (Tachinidae) on several Lepidopterans[J]. Environmental Entomology, 1976, 5(6): 1146-1148.
- [44] Soteres K M, Berberet R C, McNew R W. Parasitic insects associated with Lepidopterous herbivores on Alfalfa in Oklahoma[J]. Environmental Entomology, 1984, 13(3): 787-793.
- [45] Sisay B, Simiyu J, Malusi P, *et al.* First report of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), natural enemies from Africa[J]. Journal of Applied Entomology, 2018, 142(8): 800-804.
- [46] Bianchi F A. The recent introduction of armyworm (*S. exempta*, *S. exigua*, *S. frugiperda*) parasites from Texas[J]. Hawaii Planter's Record, 1944, 48: 203-212.
- [47] Andrews K L. Latin American research on *Spodoptera frugiperda* (Lepidoptera: Noctuidae)[J]. Florida Entomologist, 1988, 71(4): 630-653.
- [48] Wheeler G S, Ashley T R, Andrews K L. Larval parasitoids and pathogens of the fall armyworm in honduran maize[J]. Entomophaga, 1989, 34(3): 331-340.
- [49] Cruz I, Figueiredo M L C, Valicente F H, *et al.* Application rate trials with a nuclear polyhedrosis virus to control *Spodoptera frugiperda* (Smith) on maize[J]. Anais da Sociedade Entomológica do Brasil, 1997, 26(1): 145-152.
- [50] Tingle F C, Mitchell E R, McLaughlin J R. Lepidopterous pests of cotton and their parasitoids in a double-cropping environment[J]. Florida Entomologist, 1994, 77(3): 334-341.
- [51] Meagher J R L, Nuessly G S, Nagoshi R N, *et al.* Parasitoids attacking fall armyworm (Lepidoptera: Noctuidae) in sweet corn habitats[J]. Biological Control, 2016, 95: 66-72.
- [52] Fiaboe K K M, Fernandez-Triana J, Nyaum F W, *et al.* *Cotesia icipe* sp. n., a new Microgastrinae wasp (Hymenoptera, Braconidae) of importance in the biological control of Lepidopteran pests in Africa[J]. Journal of Hymenoptera Research, 2017, 61: 49-64.
- [53] Silva R B, Cruz I, Pentead-Dias A M. First report of *Dolichozele koebelei* viereck, 1911 (Hymenoptera: Braconidae) on larvae of *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae) in maize (*Zea mays* L.) under different cropping systems[J]. Brazilian Journal of Biology, 2014, 74(3): 218-222.
- [54] Pentead-Dias A M, Figueiredo M L C, Dias M M, *et al.* First host for *Exasticolus fuscicornis* (Cameron, 1887) (Hymenoptera: Braconidae: Homolobinae)[J]. Zoologische Mededeelingen, 2006, 80(1): 109-112.
- [55] Shylesha A N, Jalali S K, Gupta A, *et al.* Studies on new invasive pest *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) and its natural enemies[J]. Journal of Biological Control, 2018, 32(3): 145-151.
- [56] Prasanna B M, Huesing J E, Eddy R, *et al.* Fall armyworm in Africa: a guide for integrated pest management[M]. Mexico: CDMX: CIMMYT, 2018.
- [57] Ordóñez-García M, Rios-Velasco C, Berlanga-Reyes D I, *et al.* Occurrence of natural enemies of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Chihuahua, Mexico[J]. Florida Entomologist, 2015, 98(3): 843-847.
- [58] Pair S D, Raulston J R, Sparks A N, *et al.* Fall armyworm (Lepidoptera: Noctuidae) parasitoids: differential spring distribution and incidence on corn and sorghum in the southern united states and northeastern Mexico[J]. Environmental Entomology, 1986, 15(2): 342-348.

- [59] Lopez M A, Martinez-Castillo A M, Garcia-Gutierrez C, *et al.* Parasitoids and entomopathogens associated with fall armyworm, *Spodoptera frugiperda*, in northern Sinaloa[J]. Southwestern Entomologist, 2018, 43(4): 867-881.
- [60] Blumberg D, Ferkovich S M. Development and encapsulation of the endoparasitoid, *Microplitis croceipes* (Hym.: Braconidae), in six candidate host species (Lep.)[J]. Entomophaga, 1994, 39(3-4): 293-302.
- [61] Rajapakse R H S, Ashley T R, Waddill V H. Biology and host acceptance of *Microplitis manilae* (Hymenoptera: Braconidae) raised on fall armyworm larvae, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)[J]. Florida Entomologist, 1985, 68(4): 653-657.
- [62] Mccutcheon G S, Harrison W. Host range and development of *Microplitis rufiventris* (Hymenoptera: Braconidae) an imported parasitoid of several lepidopterous pests[J]. Environmental Entomology, 1987, 16(4): 855-858.
- [63] 陈壮美, 赵琳超, 刘航, 等. 斯氏侧沟茧蜂对草地贪夜蛾幼虫的寄生行为及寄生效应[J]. 植物保护, 2019. DOI: 10.16688/j.zwbh.2019341.
- [64] Riggan T M, Wiseman B R, Isenhour D J, *et al.* Incidence of fall armyworm (Lepidoptera: Noctuidae) parasitoids on resistant and susceptible corn genotypes[J]. Environmental Entomology, 1992, 21(4): 888-895.
- [65] Hofmaster R N, Greenwood D E. Fall armyworm control on forage and truck crops[J]. Journal of Economic Entomology, 1949, 42(3): 502-506.
- [66] Molina-Ochoa J, Carpenter J E, Lezama-Gutiérrez R, *et al.* Natural distribution of Hymenopteran parasitoids of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae in Mexico[J]. Florida Entomologist, 2004, 87(4): 461-472.
- [67] Bultman T L, Rodstrom J L, Radabaugh K R, *et al.* Influence of genetic variation in the fungal endophyte of a grass on an herbivore and its parasitoid[J]. Entomologia Experimentalis et Applicata, 2009, 130(2): 173-180.
- [68] Murua G, Virla E G. Contribution to the biological knowledge of *Euplectrus platyhypenae* (Hymenoptera: Eulophidae), a parasitoid of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Argentina[J]. Folia Entomologica Mexicana, 2004, 43(2): 171-180.
- [69] Paron M R, Berti-Filho E. Reproductive capacity of *Trichospilus diatraeae* (Hymenoptera: Eulophidae) on different host pupae (Lepidoptera)[J]. Scientia Agricola, 2000, 57(2): 355-358.
- [70] Silva R B, Cruz I, Figueiredo M L C, *et al.* Record of new species of parasitoids on larvae of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) and *Dichomeris famulata* Meyrick (Lepidoptera: Gelechiidae) in maize (*Zea mays* L.) in Brazil[J]. Revista Brasileira de Milho e Sorgo, 2012, 11(1): 125-129.
- [71] Ashley T R. Classification and distribution of fall armyworm parasites[J]. The Florida Entomologist, 1979, 62(2): 114-123.
- [72] Barbosa P, Saunders J A, Kemper J, *et al.* Plant allelochemicals and insect parasitoids effects of nicotine on *Cotesia congregata* (Say) (Hymenoptera: Braconidae) and *Hyposoter annulipes* (Cresson) (Hymenoptera: Ichneumonidae)[J]. Journal of Chemical Ecology, 1986, 12(6): 1319-1328.
- [73] Escalante G J A. Contribution to the knowledge of the biology of *Heliothis zea* and *Spodoptera frugiperda* in Cusco[J]. Revista Peruana de Entomologia, 1974, 17(1): 121-122.
- [74] Garcia-Gutierrez C, Gonzalez-Maldonado M B, Gonzalez-Hernandez A. Natural parasitism of Braconidae and Ichneumonidae (Hymenoptera) on *Spodoptera frugiperda* (Lepidoptera: Noctuidae)[J]. Revista Colombiana de Entomologia, 2013, 39(2): 211-215.
- [75] Canas L A, O'Neil R J. Applications of sugar solutions to maize, and the impact of natural enemies on fall armyworm[J]. International Journal of Pest Management, 1998, 44(2): 59-64.
- [76] Pair S D, Gross H R. Seasonal incidence of fall armyworm (Lepidoptera: Noctuidae) pupal parasitism in corn by *Diapetimorpha introita* and *Cryptus albitarsis* (Hymenoptera: Ichneumonidae)[J]. Journal of Entomological Science, 1989, 24(3): 339-343.
- [77] Pair S D, Gross H R. Field mortality of pupae of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), by predators and a newly discovered parasitoid, *Diapetimorpha introit*[J]. Journal of the Georgia Entomological Society, 1984, 19(1): 22-26.
- [78] Sueldo M R, Bruzzone O A, Virla E G. Characterization of the earwig, *Doru lineare*, as a predator of larvae of the fall armyworm, *Spodoptera frugiperda*: a functional response study[J]. Journal of Insect Science, 2010, 10(1): 38.
- [79] Reis L L, Oliveira L J, Cruz L. Biology and potential of *Doru luteipes* for the control *Spodoptera frugiperda*[J]. Pesquisa Agropecuaria Brasileira, 1988, 23(4): 333-342.
- [80] Kharboubli M S, Mack T P. Effect of temperature, humidity, and prey density on feeding rate of the striped earwig (Dermaptera: Labiduridae)[J]. Environmental Entomology, 1993, 22(5): 1134-1139.

- [81] Silva A B, Batista J L, Brito C H. Aspectos biológicos de *Euborellia annulipes* sobre ovos de *Spodoptera frugiperda* [J]. Engenharia Ambiental, 2009, 6(3): 482-495.
- [82] Silva A B, Cruz I, Figueiredo M L C, *et al.* Development of *Coleomegilla maculata* De Geer (Coleoptera: Coccinellidae) with prey and artificial diet[J]. Revista Brasileira de Milho e Sorgo, 2010, 9(1): 13-26.
- [83] Marti O G Jr, Hamm J J. Effect of *Vairimorpha* sp. on the survival of adult *Calleida decora* in the laboratory[J]. Journal of Agricultural Entomology, 1986, 3(3): 242-248.
- [84] Allen R T. *Calosoma (Castrida) alternans granulatum* Perty: a predator of cotton leaf worms in Bolivia (Coleoptera: Carabidae: Carabini)[J]. The Coleopterists Bulletin, 1977, 31(1): 73-76.
- [85] Young O P, Hamm J J. Compatibility of two fall armyworm pathogens with the predaceous beetle, *Calosoma sayi* (Coleoptera: Carabidae)[J]. Journal of Entomological Science, 1985, 20(2): 212-218.
- [86] Nachappa P, Braman S K, Guillebeau L P, *et al.* Functional response of the tiger beetle *Megacephala carolina carolina* (Coleoptera: Carabidae) on *Twolined Spittlebug* (Hemiptera: Cercopidae) and fall armyworm (Lepidoptera: Noctuidae)[J]. Journal of Economic Entomology, 2006, 99(5): 1583-1589.
- [87] Bass J A, Shepard M. Predation by *Sycanus indagator* on larvae of *Galleria mellonella* and *Spodoptera frugiperda*[J]. Entomologia Experimentalis et Applicata, 1974, 17(2): 143-148.
- [88] Cogni R, Freitas A V L, Filho F A. Influence of prey size on predation success by *Zelus longipes* L. (Het: Reduviidae)[J]. Journal of Applied Entomology, 2000, 126(2-3): 74-78.
- [89] Su H H, Tian J C, Naranjo S E, *et al.* *Bacillus thuringiensis* plants expressing *cry1ac*, *cry2ab* and *cry1f* are not toxic to the assassin bug, *Zelus renardii*[J]. Journal of Applied Entomology, 2015, 139(1-2): 23-30.
- [90] Joseph S V, Braman S K. Predatory potential of *Geocoris* spp. and *Orius insidiosus* on fall armyworm in resistant and susceptible Turf[J]. Journal of Economic Entomology, 2009, 102(3): 1151-1156.
- [91] 赵雪晴, 刘莹, 石旺鹏, 等. 东亚小花蝽对草地贪夜蛾幼虫的捕食效应[J]. 植物保护, 2019, DOI: 10.16688/j.zwbh.2019375.
- [92] CABI. *Nabis capsiformis* (pale damsel bug)[EB/OL]. 2019. <https://www.cabi.org/isc/datasheet/35656>.
- [93] 唐艺婷, 李玉艳, 刘晨曦, 等. 蝽蟓对草地贪夜蛾的捕食能力评价和捕食行为观察[J]. 植物保护, 2019, 45(3): 65-68.
- [94] Medal J, Cruz A S, Smith T. Feeding responses of *Euthyrhynchus floridanus* (Heteroptera: Pentatomidae) to *Megacopta cribraria* (Heteroptera: Plataspidae) with *Spodoptera frugiperda* and *Anticarsia gemmatilis* (Lepidoptera: Noctuidae) larvae as alternative prey[J]. Journal of Entomological Science, 2017, 52(1): 87-91.
- [95] 唐艺婷, 王孟卿, 陈红印, 等. 益蝽对草地贪夜蛾的捕食能力评价和捕食行为观察[J]. 中国生物防治学报, 2019, DOI: 10.16409/j.cnki.2095-039x.2019.04.005.
- [96] CABI. *Podisus connexivus*[EB/OL]. <https://www.cabi.org/isc/datasheet/39342#tonaturalEnemyOf>.
- [97] Hough-Goldstein J, Cox J, Armstrong A. *Podisus maculiventris* (Hemiptera: Pentatomidae) predation on ladybird beetles (Coleoptera: Coccinellidae)[J]. Florida Entomologist, 1996, 79(1): 64-68.
- [98] Malaquias J B, Omoto C, Ramalho F S, *et al.* Bt cotton and the predator *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) in the management of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) resistance to lambda-cyhalothrin[J]. Journal of Pest Science, 2015, 88(1): 57-63.
- [99] Zanuncio J C, Batalha V C, Guedes R N C, *et al.* Insecticide selectivity to *Supputius cincticeps* (Stal) (Het., Pentatomidae) and its prey *Spodoptera frugiperda* (J. E. Smith) (Lep., Noctuidae) [J]. Journal of Applied Entomology, 1998, 122(1-5): 457-460.
- [100] Silva Nunes G, Nascimento I N, Souza G M M, *et al.* Biological aspects and predation behavior of *Ceraeochrysa cubana* against *Spodoptera frugiperda*[J]. Revista Brasileira de Ciencias Agrarias, 2017, 12(1): 20-25.
- [101] 徐庆宣, 王松, 田仁斌, 等. 大草蛉对草地贪夜蛾捕食潜能研究[J]. 环境昆虫学报, 2019, 41(4): 754-759.
- [102] Morales-Reyes C, Rodriguez-Contreras J, Sanchez-Pedraza F, *et al.* Activity of entomopathogenic fungi against fall armyworm, *Spodoptera frugiperda*: comparison of conidia produced on artificial media and insect hosts[EB/OL]. 2013, <https://esa.confex.com/esa/2013/webprogram/Paper77424.html>.
- [103] Tavares W S, Cruz I, Silva R B, *et al.* Prey consumption and development of *Chrysoperla externa* (Neuroptera: Chrysopidae) on *Spodoptera frugiperda*

- (Lepidoptera: Noctuidae) eggs and larvae and *Anagasta kuehniella* (Lepidoptera: Pyralidae) eggs[J]. Maydica, 2011, 56(3): 283-289.
- [104] Perfecto I. Indirect and direct effects in a tropical agroecosystem: the maize-pest-ant system in Nicaragua[J]. Ecology, 1990, 71(6): 2125-2134
- [105] Machado V L L, Gobbi N, Simões D. Prey items utilized by *Stelopolybia pallipes* (Olivier, 1791) (Hym. Vespidae)[J]. Anais Da Sociedade Entomológica Do Brasil, 1984, 14(1): 73-79.
- [106] Okuma D M, Bernardi D, Horikoshi R J, *et al.* Inheritance and fitness costs of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) resistance to spinosad in Brazil[J]. Pest Management Sciences, 2017, 74(6): 1441-1448.
- [107] Yu S J. Insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J. E. Smith)[J]. Pesticide Biochemistry and Physiology, 1991, 39(1): 84-91.
- [108] Cave R D. Biology, ecology and use in pest management of *Telenomus remus*[J]. Biocontrol News and Information, 2000, 21(1): 21-26.
- [109] Hernandez D, Ferrer F, Linares B. Introduccion de *Telenomus remus* Nixon (Hym.: Scelionidae) para controlar *Spodoptera frugiperda* (Lep.: Noctuidae) en Yaritagua-Venezuela[J]. Agronomía Tropical, 1989, 39(4-6): 199-205.
- [110] Figueiredo M L C, Cruz I, Silva R B, *et al.* Biological control with *Trichogramma pretiosum* increases organic maize productivity by 19.4%[J]. Agronomy for Sustainable Development, 2015, 35(3): 1175-1183.
- [111] Neto F C M, Cruz I, Zanuncio J C, *et al.* Parasitism by *Campoletis flavicincta* on *Spodoptera frugiperda* in corn[J]. Pesquisa Agropecuária Brasileira, 2004, 39(11): 1077-1081.
- [112] Day R, Abrahams P, Bateman M, *et al.* Fall armyworm: impacts and implications for Africa[J]. Outlooks on Pest Management, 2018, 28(5): 196-201.
- [113] 王燕, 张红梅, 尹艳琼, 等. 蠋蝽成虫对草地贪夜蛾不同龄期幼虫的捕食能力[J]. 植物保护, 2019, DOI: 10.16688/j.zwbh.2019346.
- [114] 中国农业科学院植物保护研究所. 植保所率先开展以天敌昆虫防控草地贪夜蛾的试验与应用[EB/OL]. 2019, <http://www.ipcaas.cn/xwtt/192456.htm>.
- [115] 赵英杰, 郑亚强, 符成悦, 等. 异色瓢虫对草地贪夜蛾 2 龄幼虫的捕食功能反应[J]. 植物保护, 2019, DOI: 10.16688/j.zwbh.2019370.