

橘小实蝇天敌种类及其应用研究进展*

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摘 要 橘小实蝇 *Bactrocera dorsalis* (Hendel) 是一种广泛分布于亚洲及夏威夷群岛等地的入侵有害生物, 对我国的水果和蔬菜造成了严重的影响。橘小实蝇的防治大多使用化学杀虫剂, 然而化学杀虫剂的大量使用会导致橘小实蝇产生不同程度的抗性, 同时也会杀伤其天敌, 防治变得越来越困难; 相较于化学防治, 在不同地区筛选有效的天敌对橘小实蝇进行生物防治是有效控制的绿色防控措施, 契合我国农业农村部大力推进特色优势农作物病虫害绿色防控的工作重点。目前, 国内外报道的橘小实蝇寄生性天敌有 70 余种; 捕食性天敌主要为蚂蚁、螳螂、隐翅虫、螨、蜘蛛、步行虫等; 寄生性微生物主要为真菌、细菌、病原线虫、共生菌等; 食虫动物主要为鸡、鸟等。橘小实蝇生物防治中, 多天敌资源的联合利用可有效增强防治效果。因此, 本文系统全面地整理了国内外可查的橘小实蝇天敌种类, 以及部分优势单种或多种组合的控害潜能, 以期对橘小实蝇天敌种类的筛选和高效的生物防治应用提供参考。

关键词 橘小实蝇; 生物防治; 天敌昆虫; 控害潜能

Progress in research on natural enemies of the oriental fruit fly, *Bactrocera dorsalis* and the application of these in the biological control of this pest

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Abstract *Bactrocera dorsalis* Hendel is an invasive pest widely distributed in Asia and the Hawaiian Islands that causes serious damage to fruit and vegetable crops. The prevention and control of *B. dorsalis* mainly relies on chemical insecticides but extensive use of these has not only caused different degrees of resistance to emerge in *B. dorsalis* populations, but also kills the natural enemies of this pest, making control progressively more difficult. Biological control is an important alternative to pesticides for the control of *B. dorsalis*. Currently more than 70 species of parasitic natural enemies of *B. dorsalis* have been identified in China and abroad. Predatory natural enemies are mainly ants, earwigs, rove beetles, mites, spiders and birds, whereas parasitic microorganisms are mainly fungi, bacteria, nematodes and symbiotic bacteria. Deploying multiple biological control agents is generally preferable to a single agent. This paper systematically and comprehensively categorizes the available domestic and foreign natural enemies of *B. dorsalis*, and assesses the potential of using individual species or multi-species combinations for the biological control of this pest.

Key words *Bactrocera dorsalis* Hendel; biological control; natural enemy insect; potential of pest control

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橘小实蝇 *Bactrocera dorsalis* (Hendel) 隶属双翅目 Diptera, 实蝇科 Tephritidae, 寡鬃实蝇亚科 Dacinae, 亦称“东方果实蝇”, 俗称针蜂、果蛆和黄苍蝇等。因橘小实蝇具有较强的扩散性及适应性而被认为是最具破坏力的入侵性害虫之一(潘志萍等, 2005)。该虫起源于亚洲地区, 目前已入侵至少 65 个国家和地区(<https://www.cabi.org/isc/datasheet/17685>)。在我国, 该虫自 1911 年在台湾地区首次报道以来, 现已广泛分布于福建、湖南、广东、广西、云南、贵州、海南、四川、台湾、香港、河南、陕西等省市和地区(谢琦和张润杰, 2005; 梁靛和李毅然, 2017; 毛红彦等, 2019; 巫辅民, 2019), 且危害区域有北移的趋势(王涤非, 2019)。橘小实蝇的寄主多达 46 科 450 种, 常造成严重的经济损失(梁帆等, 2008; Salmah *et al.*, 2018; Wei *et al.*, 2019)。目前, 对其的防控仍以化学防治为主, 并且该虫已对多种化学药剂产生了抗药性(潘志萍等, 2005; 章玉苹等, 2007, 2008a)。近年来, 大力推进特色优势农作物病虫害绿色防控逐渐成为我国农业农村部工作重点之一。因此, 针对果蔬重大害虫橘小实蝇开发绿色防控迫在眉睫。

天敌是橘小实蝇绿色防控中的关键技术之一(潘志萍等, 2018; Heve *et al.*, 2021)。橘小实蝇的天敌种类丰富, 主要有寄生性天敌、捕食性天敌、寄生性微生物和食虫动物等(Migani *et al.*, 2016; 潘志萍等, 2018; 莫晟琼等, 2021)。国外利用天敌防治橘小实蝇较早, 其中以利用寄生性天敌控制橘小实蝇种群数量的研究居多, 而我国近十多年来才开展该方面的研究工作(Ables and Shepard, 1976; 季清娥等, 2004)。中国地大物博, 昆虫资源丰富, 充分挖掘我国橘小实蝇天敌资源, 对开展橘小实蝇的绿色防控具有重要意义。此外, 已有研究表明多种天敌联合应用已成为增强其生物防治效果的发展趋势(吕增印等, 2008a; 陈佳等, 2011)。因此, 本文综述了国内外橘小实蝇天敌种类、优势种的应用及多种天敌联合应用的情况, 以期为我国橘小实蝇生物防治策略的制定提供科学依据。

1 橘小实蝇的天敌种类

橘小实蝇天敌种类繁多, 目前国内外已研究的橘小实蝇天敌主要有寄生性天敌(表 1)、捕食性天敌(表 2)、寄生性微生物(表 3)和食虫动物, 其中以寄生性天敌居多, 达 70 余种。

寄生性天敌主要包括 2 种卵-幼虫跨期寄生蜂, 4 种幼虫-蛹跨期寄生蜂, 4 种幼虫寄生蜂和 6 种蛹期寄生蜂。其中阿里山潜蝇茧蜂 *Fopius arisanus*(Sonan)、长尾潜蝇茧蜂 *Diachasmimorpha longicaudata*(Ashmead)、布氏潜蝇茧蜂 *F. vandenboschi*(Fullway)、切割潜蝇茧蜂 *Psytalia Incisi*(Silvestri)和东方实蝇蛹俑小蜂 *Spalangia endius*(Walker)在国内外均有报道; *F. ceratitivorus*(Wharton)、*D. tryoni*(Cameron)、布氏短背茧蜂 *P. fletcheri*(Silvestri)、实蝇啮小蜂 *Tetrastichus giffardianus* Silvestri、*P. incisi*(Silvestri)、吉氏角头小蜂 *Dirhinus giffarddi*(Silvestri)、匙胸瘿蜂属 *Aganaspis* sp.在国内未见相关文献; 印度实蝇姬小蜂 *Aceratoneuromyia indica*(Silvestri)、长柄俑小蜂 *Spalangia Longepetiolata*(Boucek)和蝇蛹金小蜂 *Pschycropoideus vindemmiae*(Rondani)仅仅在国内有报道。在橘小实蝇寄生性天敌中, 阿里山潜蝇茧蜂为优势种, 研究报道最多。该寄生蜂主要寄生于处于静止状态、防御能力弱的卵, 故在寄生蜂中占有绝对优势(Wang *et al.*, 2003; 宋学森, 2019)。此外, 切割潜蝇茧蜂和长尾潜蝇茧蜂已能大量繁殖, 且在田间释放控制橘小实蝇的种群数量有一定的防效(梁光红和陈家骅, 2006; 邵屯等, 2008; 胡婉晴, 2019)。

关于橘小实蝇捕食性天敌国外研究较多, 国内少有报道。主要有 2 种蚂蚁, 2 种蠋螋, 1 种隐翅虫和 3 种蝽类。这几类捕食性天敌中, 长结织叶蚁 *Oecophylla longinoda* 和红火蚁 *Solenopsis invicta* 在橘小实蝇防治中有一定的应用(Cao *et al.*, 2012; Chailleux *et al.*, 2019; Mekonnen *et al.*, 2021)。但红火蚁是一种入侵性蚂蚁, 现已入侵我国长江流域以南不少地区, 且对入侵地生物多样性造成了严重影响, 且对我国生物多样性造成了严重影响, 属于重点防控对象(陆永跃

表 1 橘小实蝇主要寄生性天敌种类
Table 1 Species of major parasitic natural enemies of *Bactrocera dorsalis*

科 Families	种 Species	寄生虫态 Parasitism stage	寄生率 (%) Parasitism rate	参考文献 References
茧蜂科 Braconidae	阿里山潜蝇茧蜂 <i>Fopius arisanus</i> (Sonan)	卵、初孵幼虫和蛹 Eggs, newly hatched larvae and pupae	41.0-72.0	郭庆亮等，2006，2015； Vargas <i>et al.</i> , 2007; 耿军灵， 2009; Groth <i>et al.</i> , 2016; Ayelo <i>et al.</i> , 2017
	<i>F. ceratitivorus</i> (Wharton)	卵、初孵幼虫和蛹 Eggs, newly hatched larvae and pupae	/	Bokonon-Ganta <i>et al.</i> , 2005
	长尾潜蝇茧蜂 <i>Diachasmimorpha longicaudata</i> (Ashmead)	老熟幼虫和蛹 Mature larvae and pupae	10.0-23.0	Duan and Messing, 1997； Purcell <i>et al.</i> , 1997; 林玲等， 2006; 陈科伟等，2012; 王 勇，2013
	<i>D. tryoni</i> (Cameron)	幼虫和蛹 Larvae and pupae	/	Vargas <i>et al.</i> , 2002
	布氏潜蝇茧蜂 <i>F. vandenboschi</i> (Fullway)	低龄幼虫 Young larvae	33.6	Ramadan, 2004; 吕增印， 2008；吕增印等 2008a， 2008b; 章玉苹等，2008b
	布氏短背茧蜂 <i>Psytalia fletcheri</i> (Silvestri)	幼虫 Larvae	/	Vargas <i>et al.</i> , 2002
	切割潜蝇茧蜂 <i>P. incisi</i> (Silvestri)	低龄幼虫和蛹 Young larvae and pupae	20.0	Bautista and Harris, 1997； 季清娥等，2004; 梁光红等， 2006，2007
	<i>Biosteres persulcatus</i> (Silvestri 1916)	幼虫 Larvae	75.0	Ibrahim <i>et al.</i> , 1993
姬小蜂科 Eulophidae	印度实蝇姬小蜂 <i>Aceratoneuromyia indica</i> (Silvestri)	幼虫和蛹 Larvae and pupae	43.8	章玉苹等，2009; 韩群鑫等， 2013
	实蝇啮小蜂 <i>Tetrastichus giffardianus</i> Silvestri	幼虫 Larvae	/	Purcell <i>et al.</i> , 1996
金小蜂科 Pteromalidae	东方实蝇蛹小蜂 <i>Spalangia endius</i> (Walker)	蛹 Pupae	50.0-61.1	Ables and Shepard, 1976； 唐良德等，2015; 赵海燕等， 2015，2016
	长柄蛹小蜂 <i>S. longepetiolata</i> (Boucek)	蛹 Pupae	/	郑敏琳等，2006
	蝇蛹金小蜂 <i>Pschycropoideus vindemmiae</i> (Rondani)	蛹 Pupae	/	Wang and Messing, 2004a； 林文超，2007
	<i>P. incisi</i> (Silvestri)	蛹 Pupae	/	Wang and Messing, 2004b
小蜂科 Chalcididae	吉氏角头小蜂 <i>Dirhinus giffarddi</i> (Silvestri)	蛹 Pupae	/	Wang and Messing, 2004a； Okuyama, 2016; Ullah <i>et al.</i> , 2021
匙胸瘿蜂 Eucoilidae	匙胸瘿蜂属 <i>Aganaspis</i> sp.	蛹 Pupae	/	Stibick, 2004；Ovruski <i>et al.</i> , 2007

/表示没有相关文献记录。/ indicats no record of references.

表 2 橘小实蝇主要捕食性天敌种类
Table 2 Species of major predatory natural enemies of *Bactrocera dorsalis*

科 Families	种 Species	捕食虫态 Predatory stage	参考文献 References
隐翅虫 Staphylinidae	<i>Spalangia</i> sp.	幼虫 Larvae	Takara and Nishida, 1981
蠅虻科 Labiduridae	<i>Anisolabis eternoma</i>	幼虫 Larvae	
	<i>Sphingolabis hawaiiens</i>	幼虫 Larvae	
花蝽科 Anthicoridae	小花蝽 <i>Orius insidiosus</i> (Say)	卵 Egg	
蚁科 Formicidae	红火蚁 <i>Solenopsis invicta</i>	蛹和初羽化成虫 Pupae and newly emerged adults	Cao <i>et al.</i> , 2012
	长结织叶蚁 <i>Oecophylla longinoda</i>	卵和幼虫 Egg and larvae	Abdulla <i>et al.</i> , 2017; Chailleux <i>et al.</i> ; 2019; Diame <i>et al.</i> , 2015; Migani <i>et al.</i> , 2016; Van Mele <i>et al.</i> , 2009

表 3 橘小实蝇主要寄生性微生物天敌种类
Table 3 Species of major parasitic microbial natural enemies of *Bactrocera dorsalis*

科 Families	种 Species	作用虫态 Role in insect stage	参考文献 References
共生菌 Symbiotic bacteria	<i>Nosema tephritidae</i>	成虫 Adults	Fujii and Tamashiro, 1972
真菌 Fungi	球孢白僵菌	幼虫、蛹和成虫 Larvae, pupae and adults	袁盛勇等, 2010a; 潘志萍等, 2014; 潘志萍和翟欣, 2015
	<i>Beauveria bassiana</i>		
病原线虫 Plant parasitic nematode	印度小杆线虫	幼虫 Larvae	林进添等, 2005
	<i>Heterorhabditis indica</i>		
	小卷蛾斯氏线虫	幼虫 Larvae	
	<i>Steinernema carpocapsae</i>		
	夜蛾斯氏线虫 <i>S. feltiae</i>	幼虫 Larvae	
细菌 Bacteria	嗜菌异小杆线虫	幼虫和蛹 Larvae and pupae	黄天培等, 2008; 陆慧慧等, 2015
	<i>Heterorhabditis bacteriophora</i>		
	苏云金芽孢杆菌	幼虫 Larvae	
	<i>Bacillus thuringiensis</i> , Bt		

等, 2019), 因此在防控橘小实蝇方面尚无应用可行性。此外, 蚂蚁分泌物对橘小实蝇具有一定的驱避作用, 种植吸引蚂蚁的植物、配合蚂蚁引诱剂和蚂蚁驱避剂, 对防治橘小实蝇具有重要意义 (Van Mele *et al.*, 2009), 但是如何合理的引诱蚂蚁防治该虫, 需进一步研究。

橘小实蝇寄生性微生物国内外均有相关研究, 国外研究以共生菌较多。例如, 李斯特菌属 *Listeria*、柠檬酸杆菌属 *Citrobacter*、卡他莫拉菌属 *Moraxella*、变形杆菌属 *Proteus*、链杆菌属 *Streptobacillus*、肠杆菌属 *Enterobacter*、沙雷氏菌属 *Serratia*、弧形菌属 *Vibrio*、气单胞菌属 *Aeromonas*、克雷伯氏菌属 *Klebsiella*、摩根菌属

Morganella 等 (Pramanik *et al.*, 2014)。共生细菌在昆虫肠道内腔、特殊器官或细胞内产生, 为昆虫提供营养物质, 并与其天敌防治、繁殖特性、抗药性以及其它生理和生态特性有关 (Noman *et al.*, 2020), 因此, 利用共生菌防治橘小实蝇为害有一定的应用前景。国内研究有真菌 (如球孢白僵菌 *Beauveria bassiana*) (袁盛勇等, 2010a; 潘志萍等, 2014; 潘志萍和翟欣, 2015)、细菌 (如苏云金芽孢杆菌 *Bacillus thuringiensis*, Bt) (黄天培等, 2008)、病原线虫 (如小卷蛾斯氏线虫 *Steinernema carpocapsae*、夜蛾斯氏线虫 *S. feltiae* SN 品系和嗜菌异小杆线虫 *Heterorhabditis bacteriophora* H06 品系) (林进添等, 2005) 和

共生菌(如 *Actinobacteria*、*Firmicutes*、*Listeria*、*Citrobacter*、*Moraxella*、*Proteus*、*Streptobacillus*、*Enterobacter*、*Serratia*、*Vibrio*、*Aeromonas*、*Klebsiella*、*Morganella*、*Citrobacter* sp. (CF-BD) 和 *Wolbachia* 等,其中 *Actinobacteria* 和 *Firmicutes*, 只有国内有相关报道)(孙晓等, 2004; Wang *et al.*, 2011; Cheng *et al.*, 2017)。在寄生性微生物中,防治效果较好的微生物为球孢白僵菌和苏云金芽孢杆菌(Bt)。

另外,国内利用食虫动物控制橘小实蝇也有报道(莫晟琼等, 2021)。橘小实蝇老熟幼虫会从受害的虫果弹跳入土,多数在 2-3 cm 土层化蛹。果园内饲养鸡、鸟等除取食落地烂果、受害果中、地表的幼虫和成虫外,还可以取食土里的蛹,从而减少虫口基数,降低其种群密度达到防治害虫的目的(王美兰, 2008; 林来金, 2015; 王华生, 2019; 莫晟琼等, 2021)。

2 橘小实蝇优势天敌应用

综合国内外来看,阿里山潜蝇茧蜂,蚂蚁 *O. longinoda* 和 *S. invicta*,球孢白僵菌 *B. bassiana* (Balsamo) Vuillemin 和苏云金芽孢杆菌 Bt 等防治效果较好,且阿里山潜蝇茧蜂,球孢白僵菌和苏云金芽孢杆菌 Bt 等已能大量生产,已在基地示范应用时取得较好的效果,但在防治橘小实蝇中尚未广泛使用。

2.1 阿里山潜蝇茧蜂

阿里山潜蝇茧蜂主要寄生实蝇的卵和初孵 1 龄幼虫。研究表明,该蜂对橘小实蝇的寄生能力强、控制效果好。其对橘小实蝇卵的瞬时攻击率为 90.82%;平均寄生一粒卵需要的时间为 7.344 0 min,寄生最大理论值可达 213.5 粒/d(耿军灵, 2009);且该蜂的最佳释放数量在橘小实蝇田间虫口数量的 3 倍左右控制效果较好(郭庆亮等, 2006, 2015)。田间人工放蜂时,橘小实蝇暴发情况下,该蜂在位于福州市郊的武警福建总队副食生产基地的芭乐果园树上果实的平均寄生率为 45.8%,树下果实平均寄生率为 30.1%;杨桃园内树上果实平均寄生率为 33.3%,树下果

实平均寄生率为 22.1%,说明该蜂对果园隐藏的橘小实蝇的控制有竞争优势(耿军灵, 2009)。Nanga 等(2019)比较不同寄主植物时,发现该蜂的寄生率在番石榴实蝇上最高,达 56.0%。另外,该蜂与其他寄生蜂配合使用,可增强田间橘小实蝇的防效。例如,可大量生产的切割潜蝇茧蜂和长尾潜蝇茧蜂等(Wang *et al.*, 2003; 梁光红和陈家骅, 2006; 陈佳等, 2011; Yang *et al.*, 2018; 胡婉晴, 2019)。

2.2 蚂蚁

早在 1984 年已有蚂蚁捕食橘小实蝇老熟幼虫和初孵成虫的报道(Wong *et al.*, 1984)。研究表明,红火蚁对橘小实蝇的捕食速率与实蝇化蛹后的时间、土壤深度和土壤水分有关。在实蝇化蛹后的第 6 天对工蚁有显著的吸引作用;在土壤深度为 4 cm 和 6 cm 的捕食率分别为 70%和 0;在土壤含水量为 0、40%和 80%时,捕食率分别为 0、66.5%和 72.1%,对橘小实蝇数量有较好的控制效果(Cao *et al.*, 2012)。虽然,在多项外国研究结果中,红火蚁能捕食多种害虫,可为优势天敌(Cao *et al.*, 2012)。然而,红火蚁为我国入侵性害虫,属于严格防控的害虫之一,不能用于我国橘小实蝇的防控(陆永跃等, 2019)。另外, Van Mele 等(2009)研究中发现蚂蚁 *O. longinoda* 对橘小实蝇有驱避作用,其产卵行为会受到 *O. longinoda* 分泌物的影响,产卵量可减少 75%(Migani *et al.*, 2016)。蚂蚁筑巢、捕食幼虫和初孵成虫也可以控制橘小实蝇的种群。地上筑巢的蚂蚁可以造成大约 39%蛹和初孵成虫死亡,这说明蚂蚁捕食橘小实蝇的数量相当可观,但是不足以控制实蝇的数量(Van Mele *et al.*, 2009; Migani *et al.*, 2016)。目前,由于蚂蚁对橘小实蝇的驱避效果较好,为了更好地利用蚂蚁控制橘小实蝇的种群动态,已有关于蚂蚁分泌物蚂蚁驱避剂和蚂蚁引诱剂共同使用的研究,有研究表明豇豆植物对 *O. longinoda* 有引诱作用,木薯植物对 *O. longinoda* 有驱避作用,但是如何合理使用蚂蚁驱避剂保护人们免受蚂蚁的危害和如何使用蚂蚁引诱剂吸引蚂蚁防治橘小实蝇仍需进一步研究(Chailleux *et al.*, 2019)。

2.3 球孢白僵菌

球孢白僵菌可寄生于橘小实蝇的幼虫、蛹和成虫, 但该菌对橘小实蝇的致病力大小与寄生虫态、菌株和环境有关 (潘志萍和翟欣, 2015)。第一, 球孢白僵菌单株对橘小实蝇不同虫态的致病力不同。潘志萍等 (2006) 研究发现球孢白僵菌对橘小实蝇的致病力为成虫>蛹>老熟幼虫>卵, 其在孢子数为 1.2×10^8 个/mL 的浓度下, 球孢白僵菌对橘小实蝇成虫和蛹的侵染力分别为 83.3% 和 63.7%, 对幼虫的侵染率最低, 而对卵几乎不侵染, 即不产生致病性。然而, 袁盛勇等 (2010b) 研究得出的结论为球孢白僵菌 MZ041016 菌株对橘小实蝇各虫态的毒力效果依次是幼虫>成虫>蛹, 与潘志萍等 (2006) 的结论不太一致, 这可能与不同菌株对橘小实蝇的致病力差异有关。第二, 球孢白僵菌对橘小实蝇的致病力还与温湿度关系密切。当温度为 25 °C 时白僵菌对实蝇的致病力最强, 且此温度为球孢白僵菌防治橘小实蝇的最适温度; 白僵菌对橘小实蝇的致病力随着相对湿度的增加而增强, 当相对湿度 90%-100% 时, 橘小实蝇的死亡率最高 (潘志萍等, 2008)。此外, 在田间应用时, 喷施 2.0×10^8 孢子/mL 球孢白僵菌孢子悬浮液于树冠和土表层, 防治效果较好, 达 46.9% (潘志萍等, 2014)。

2.4 苏云金芽孢杆菌

苏云金芽孢杆菌 (*Bacillus thuringiensis*, Bt) 是一种内生芽孢革兰氏阳性土壤细菌, 对 100 多种昆虫有不同程度致病力和毒杀作用。研究发现 Bt 的 cry2Ac4 蛋白对橘小实蝇幼虫具有显著的毒杀作用, 在 72 h 内的毒杀作用达 90% (黄天培等, 2008)。苏云金芽孢杆菌 CPB012 菌株含有杀虫蛋白 cry1Aa、cry1Ia、cry2Aa、cry2Ab 和 vip3A, 处理 7 d 后对橘小实蝇的毒杀率为 76.72% (陆慧慧等, 2015)。该杀虫活性蛋白为橘小实蝇的生物防治提供技术支撑。以半固体态废水污泥为培养基原料生产 Bt, 降低了生产成本, 同时增强了对橘小实蝇幼虫的毒杀作用 (Syazwanee et al., 2016)。

2.5 橘小实蝇天敌的联合应用研究

多种天敌资源联合使用有利于提高害虫的防治效果, 增强群落稳定性, 通过增加相同食物链中生物多样性来减少天敌种群的自然衰退。在天敌的联合应用方面已有不少成功的例子, 如利用白僵菌颗粒剂和捕食螨 *Stratiolaelaps scimitus* 控制西花蓟马 *Frankliniella occidentalis*、联合应用胡瓜钝绥螨 *Neoseiulus cucumeris* 和海氏桨角蚜小蜂 *Eretmocerus hayati* 防治烟粉虱 *Bemisia tabaci* 等 (李茂海, 2017; 张兴瑞, 2019)。因此, 橘小实蝇天敌的联合应用将有利于对其综合防控。郑思宁等 (2013) 配合使用阿里山潜蝇茧蜂、不育雄虫和引诱剂来防治橘小实蝇, 田间防效达 90%。另外, 阿里山潜蝇茧蜂与长尾潜蝇茧蜂同时存在于橘小实蝇体内时, 寄生蜂总的平均羽化率 (75.95%) 比单独 1 种蜂 (阿里山潜蝇茧蜂或长尾潜蝇茧蜂) 的羽化率都高 (陈佳等, 2011; Yang et al., 2018); 寄主供阿里山潜蝇茧蜂寄生后再供切割潜蝇茧蜂寄生, 造成寄主幼虫期及蛹期的大量死亡, 蛹期死亡率高达 50.84% (陈佳, 2010); 在室内试验条件下, 为阿里山潜蝇茧蜂和弗氏短背茧蜂 *Pasytalia fletcher* 提供足量瓜实蝇的卵, 24 h 内, 阿里山潜蝇茧蜂能寄生 45% 的卵, 弗氏短背茧蜂能寄生 90% 的卵, 两者联合寄生率达到 93% (Bautista et al., 2004), 这表明寄生蜂联合应用防治橘小实蝇具有增效性。此外, 在合适的温湿度条件下, 选择适量的白僵菌与高效低毒杀虫剂混用或者其他绿色防控手段配合使用, 是联用增效的又一手段。在桃实蝇 *Bactrocera zonata* (Saunders) 的防治中, 化学药剂搭配白僵菌的幼虫死亡率高于单独施药 (Ibrahim and Soliman, 2020)。

此外, 橘小实蝇体内已发现共生菌沃尔巴克氏体 *Wolbachia*, 已知 *Wolbachia* 可侵染大约 20% 的昆虫种类, 对实蝇的感染率为 28.13%, 影响寄主的生殖活动 (孙晓等, 2004), 具有广泛应用于实蝇不育防治技术的潜力 (Mateos et al., 2020)。可见, 橘小实蝇天敌的联合应用方面已开展了一些探索, 但其在生产中推广还有待于进一步研究。

3 问题与展望

生物防治是橘小实蝇有效的绿色防控手段, 尽管已有单一天敌类群的控制效果报道, 但是实践中橘小实蝇单一的生物防治手段不能够完全控制其种群数量。特别是入侵橘小实蝇与本地实蝇混合发生时, 更需要考虑多种生物防治手段的有机结合 (Heve *et al.*, 2021)。因此, 在利用天敌防治橘小实蝇时, 可以从以下几点考虑: 第一, 需要根据不同的环境条件以及不同寄生蜂的特性, 选择合适的寄生蜂联合使用。如寄生蜂密度、寄主密度、寄主龄期和环境因子等。第二, 根据橘小实蝇与捕食性天敌之间的相互关系和植物-害虫-天敌之间的相互作用特点, 在植物周围种植能够吸引捕食性天敌的植物或使用引诱剂, 开发橘小实蝇驱避剂, 共同控制橘小实蝇。第三, 根据橘小实蝇的种群特点和环境条件, 适时适量地配合生防微生物制剂。第四, 根据实际情况适当在果园环境中引入食虫动物。因此, 根据具体情况选择合适的天敌联合使用, 可提高橘小实蝇生物防治的效果, 增强天敌群落稳定性, 是利用天敌防治橘小实蝇的必然趋势, 具有可持续性和广阔前景。

然而, 实际生产中天敌防治橘小实蝇的效果常受多种因素影响。首先, 生物防治与化学防治普遍存在兼容性的问题, 化学防治手段也会对天敌有一定的杀灭作用。目前, 橘小实蝇的防治仍以化学药剂为主, 且其抗药性逐年增强 (Jin *et al.*, 2011; Wei *et al.*, 2019; 何凤梅等, 2020)。考虑到天敌防治作用较慢, 对田间系统的持续控制时间长, 因此, 必须合理使用农药、严格限制或禁止使用化学农药, 特别是广谱、剧毒的化学农药 (Wang *et al.*, 2019)。否则, 橘小实蝇的天敌防治也极易发生与油橄榄果实蝇 *B. oleae* Rossi 类似的防治手段的矛盾 (Pinheiro *et al.*, 2020)。欣慰的是, 农药对天敌的影响已经获得广泛关注 (Karamaouna *et al.*, 2021), 但是大多数研究都在室内进行, 缺乏田间实际情况的相关评估。其次, 天敌的大量饲养与释放也是橘小实蝇生物防治的技术瓶颈, 也是未来的研究热点。目前, 持

续有关橘小实蝇天敌大量饲养研究的报道 (Cai *et al.*, 2017; Ullah *et al.*, 2021)。传统的人工释放天敌耗时耗力、效率低下, 如今, 无人机技术已用于不育雄虫和天敌释放 (Zhan *et al.*, 2021), 或可在未来在橘小实蝇的防控中应用无人机释放技术同时释放不育雄虫和寄生蜂, 形成组合型防治手段。

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