

载体植物在温室作物害虫生物防治中的应用*

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摘 要 增补式生物防治是利用天敌昆虫或捕食螨防治害虫最常用的方法, 释放的天敌昆虫或捕食螨能否成功建立稳定种群, 是决定其持久高效控害的首要关键因素。然而在生产应用中, 经常因释放的天敌昆虫或捕食螨不能成功定殖而无法达到理想的防治效果。载体植物系统是天敌饲养和释放的新方法, 结合了增补式和保护式生物防治的优点, 既能实现天敌昆虫或捕食螨的大量饲养, 又能为释放的天敌昆虫或捕食螨提供替代食物和栖息场所, 促进其建立稳定的种群, 对实现天敌昆虫或捕食螨高效持久控害具有重要的意义。本文系统介绍了载体植物系统的构建、国内外研究现状, 指出了现存的问题, 并给出相应的建议。

关键词 载体植物系统; 天敌昆虫或捕食螨; 增补式生物防治; 替代寄主/猎物

Banker-plant system for biological control of pests in greenhouse-grown crops

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Abstract Augmentative biological control using predatory or parasitic insects and predatory mites is frequently applied in pest management. Establishing self-sustaining populations of released biological control agents is the key factor affecting the success of biological control. In augmentative biological control, released biological control agents cannot sustain their population size and suppress pests effectively. The Banker plant system is a new concept for biological control. This system is considered a combination of augmentative and conservation biological control strategies. The banker plants increase the survival and reproduction of biological control agents by providing alternative hosts/prey and optimal habitats, so that they can sustain a long-term suppression of pests. In this review, we summarize recent progress and theory on the utilization of banker plant systems for the biological control of crop pests under greenhouse conditions. We also discuss existing problems in banker plant system research and utilization, and make practical suggestions for implementing such systems effectively.

Key words banker plant system; natural enemy and predatory mites; augmentative biological control; alternative host/prey

近年来全球温室种植面积不断增加。截止2016年末, 我国温室面积占地 334 000 hm², 大棚面积占地 981 hm², 占世界第一 (第三次全国农业普查主要数据公报 (第二号))。温室设施作物具有显著的高产出、高经济价值等特点, 在提高土地利用率、解决粮食、蔬菜充足供应方面发挥重要的作用。温室种植的作物主要包括蔬菜、

水果与观赏植物, 这些作物上有超过 140 种的害虫和害螨, 给温室作物种植带来巨大的损失 (Heinz *et al.*, 2004)。农药的长期不合理使用造成严重的环境污染、食品安全和害虫抗药性等问题, 给人类健康和农业安全生产造成了严重威胁。因此, 以天敌昆虫或捕食螨为核心的生物防治越来越受重视。天敌昆虫或捕食螨的应用主要

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有引种式 (Classical)、保护式 (Conservative) 和增补式 (Augmentative) 三种 (Brodeur *et al.*, 2018)。引种式生物防治主要针对外来入侵害虫, 引进入侵害虫起源地天敌; 保护式生物防治是指人为促进本地天敌种群的增长; 增补式生物防治是最经常用到的方式, 即大规模饲养天敌并定期释放。在过去的几十年, 增补式生物防治发展迅速。天敌的生产从小作坊发展为标准化生产的工厂, 目前大约有 350 种天敌昆虫或捕食螨可工厂化生产, 2015 年全球天敌增补式释放面积也超过了 $3 \times 10^7 \text{ hm}^2$, 其中 80% 用于温室作物害虫的生物防治 (van Lenteren *et al.*, 2018)。然而天敌昆虫或捕食螨释放后, 经常因其不能成功定殖而无法获得持久的防治效果, 需要多次释放, 从而增加了防治成本 (van Lenteren, 2012)。因此, 如何提高天敌释放后的适应性, 促进其定殖, 实现高效持久控害, 成为现代生物防治急需解决的问题。

载体植物系统 (Banker plant system) 是一个开放式天敌饲养系统, 一般包括载体植物 (Banker plant)、替代食物 (Alternative food) 和有益生物 (Beneficials) 三个要素 (Frank, 2010; 肖英方等, 2012)。载体植物通常是非目标作物, 用于饲养替代寄主或猎物, 为有益生物提供栖息环境和食物; 某些载体植物可直接为天敌提供食物, 如花粉、花外蜜等。替代食物即替代寄主或猎物, 一般是植食性节肢动物, 不危害目标作物。载体植物系统结合了保护式和增补式生物防治的特点, 旨在创造一个可长期自我维持的天敌饲养单位 (Rearing units)。载体植物系统不仅可以在靶标害虫为害作物前预防性的建立天敌种群, 而且易于与其他防治措施 (尤其是化学农药) 结合, 实现对目标害虫的高效持久控制, 解决传统害虫生物防治的缺陷。本文对载体植物系统的构建及最新的研究应用进行了综述。

1 载体植物系统的构建

1.1 载体植物

载体植物为替代寄主或猎物与天敌昆虫或

捕食螨提供栖息场所和食物, 可直接和间接的影响替代寄主或猎物以及天敌昆虫或捕食螨的适应性, 进而影响控害效果。目前所用的载体植物主要是禾本科、茄科和菊科植物。现记录的禾本科植物作为载体植物的文献最多, 共 63 例, 其中小麦 23 例 (包括 Wheat, Bread wheat, Winter wheat) (Huang *et al.*, 2011; 邓从双等, 2014; Pan *et al.*, 2014; Pan and Liu, 2014), 大麦 8 例 (包括 Barley, Common barley) (Huang *et al.*, 2011; Prado and Frank, 2014; Jandricic *et al.*, 2014; McClure and Frank, 2015; Higashida *et al.*, 2016), 燕麦 6 例 (Huang *et al.*, 2011; Andorno and López, 2014; Jandricic *et al.*, 2014; McClure and Frank, 2015), 龙爪稷 9 例 (Huang *et al.*, 2011; Parolin *et al.*, 2013), 玉米、高粱和黑麦各 3 例 (Abe *et al.*, 2011; Huang *et al.*, 2011; Higashida *et al.*, 2017), 其他禾本科杂草 8 例 (Huang *et al.*, 2011; Wong and Frank, 2012; Xiao *et al.*, 2012; Rattanapun, 2017); 其次是茄科植物 (29 例), 其中观赏椒类 12 例 (Huang *et al.*, 2011; Xiao *et al.*, 2012; Wong and Frank, 2013; Kumar *et al.*, 2015; Lopez *et al.*, 2017), 烟草 11 例 (Huang *et al.*, 2011; Bresch *et al.*, 2014), 番茄 5 例 (Huang *et al.*, 2011), 马铃薯 1 例 (Huang *et al.*, 2011); 菊科植物能够为天敌昆虫或捕食螨提供花粉和花外蜜, 也是载体植物的重要组成部分, 现在文献记载的共 18 例, 包括藿香蓟、非洲菊、稻槎菜、金盏花等 (Huang *et al.*, 2011; Biondi *et al.*, 2016; Zhao *et al.*, 2017)。其他科的多种植物也被作为载体植物为天敌昆虫或捕食螨提供栖境和食物, 包括甜瓜、南瓜、毛蕊花、番木瓜、甘蓝、圆叶牵牛等, 共有记录 28 例 (Huang *et al.*, 2011; Parolin *et al.*, 2013, 2015a; Nakano *et al.*, 2016; Zumoffen *et al.*, 2016; Laurenz and Meyhöfer, 2017; Song *et al.*, 2017a, 2017b; Kidane *et al.*, 2018)。

载体植物的选择有以下几个原则: 首先, 载体植物生长快, 易于种植, 操作方便, 从而降低生产成本。第二, 载体植物一般为非目标栽培作

物,与栽培作物没有共同的病虫害,从而降低引进害虫的风险。Stacey (1977) 首次利用载体植物系统饲养丽蚜小蜂 *Encarsia formosa* Gahan 防治温室白粉虱 *Trialeurodes vaporariorum* (Westwood), 该研究中 Stacey 选择栽培作物番茄作为载体植物,增加了引入害虫的风险。近年来,在载体植物的构建中,研究者基本选择非目标栽培作物作为载体植物,但是部分载体植物与栽培作物具有共同的害虫,同样会增加引入害虫的风险。Schmidt (1996) 利用烟草作为载体植物,温室白粉虱作为替代寄主饲养丽蚜小蜂,用于防治香草上的粉虱,温室白粉虱即为害烟草,也为害栽培作物香草,同样具有引入害虫的风险。第三,载体植物适宜替代寄主或猎物,以及天敌昆虫或捕食螨的生长发育和繁殖。载体植物为替代寄主或猎物提供栖境和食物,直接影响它们的适合度。此外,植物挥发物是天敌搜寻寄主或猎物的重要线索 (Vinson, 1976; Powell and Wright, 1992; De Moraes *et al.*, 2001; Masters *et al.*, 2001), 可直接影响天敌对靶标害虫的搜寻效率;载体植物的种类以及品种的物理结构和抗性又能通过影响植食性昆虫的生长发育,间接影响天敌的适应性 (Pan *et al.*, 2014; Waite *et al.*, 2014; Yano *et al.*, 2018)。因此,选择载体植物时首先要测定天敌昆虫或捕食螨在该植物上的适合度。最后,载体植物要适应温室栽培环境。在许多地区,温室内的温度基本保持在 30 °C 以上,许多凉季种植的载体植物 (尤其是禾本科植物) 在此环境下无法正常生长,因此缩短了载体植物系统的寿命,提高了增补频率。

1.2 替代食物

在构建载体植物系统时,替代食物的选择也是至关重要的。替代食物主要是植食性昆虫,替代寄主和猎物 (Frank, 2010)。在载体植物系统研究初期,多种靶标害虫被选为替代寄主 (Stacey, 1977; Xu, 1991; Goolsby and Ciomperlik, 1999), 这样就会提前引入害虫。所以在后来的研究中,研究者通常选择不为害栽培

作物、但与靶标害虫有共同天敌的昆虫 (或螨类) 作为替代寄主或猎物。有的替代食物是载体植物提供的花粉和花外蜜 (Parolin *et al.*, 2015b; Nguyen-Dang *et al.*, 2016), 比如以观赏椒作为载体植物饲养捕食螨,因为观赏椒的花粉能够显著提高捕食螨的适合度 (Xiao *et al.*, 2012; Kumar *et al.*, 2015; Lopez *et al.*, 2017)。

替代寄主或猎物直接为天敌昆虫或捕食螨提供其生长发育所需要的营养,影响天敌昆虫或捕食螨的适应性和控害效果。在选择替代寄主或猎物时,首先确保能够满足天敌昆虫或捕食螨的生长发育和繁殖。虽然天敌昆虫或捕食螨可能具有多种自然寄主或猎物,但是不同种类寄主和猎物的营养和防御能力不同,从而显著影响天敌的适应性 (Rehman and Powell, 2010)。例如,豌豆蚜和桃蚜 *Myzus persicae* 均是寄生蜂 *Aphidius ervi* Haliday 的常见寄主,但是 *A. ervi* 在豌豆蚜上寄生率更高,发育更快,而且个体更大 (Daza-Bustamante *et al.*, 2003)。此外,天敌昆虫或捕食螨不能对替代寄主或猎物有很强的专化性,否则会降低其对靶标害虫的寄生或捕食效率 (Vafaie *et al.*, 2013)。

1.3 有益生物

载体植物系统里的有益生物主要是寄生性和捕食性天敌,在已发表的文献里,寄生蜂 66 例,所占比例为 50.38%;捕食性天敌昆虫 49 例,占 37.40%;捕食螨 16 例,占 12.22%。天敌是替代寄主和靶标害虫的共有天敌,并且能够在两者之间成功转换,如此替代寄主饲养的天敌才能够有效地抑制靶标害虫。

2 温室内载体植物系统的应用

温室内最早成功利用天敌昆虫防治害虫是在 1927 年,利用丽蚜小蜂防治温室白粉虱 (Speyer, 1927; Hussey 1985)。从 20 世纪 40 年代化学农药诞生以来,生物防治的发展停滞不前 (Hussey, 1985)。几年内,二斑叶螨 *Tetranychus urticae* Koch 对多种农药形成了抗性 (Bravenboer,

1959)。Bravenboer 和 Dosse (1962) 在德国种植兰花的温室内发现智利小植绥螨 *Phytoseiulus persimilis* Athias-Henriot 可以有效抑制二斑叶螨的发生, 从此, 利用生物防治控制温室害虫在欧洲开始复苏。

相对于田间种植, 生物防治更适于在温室内应用。首先温室环境易于控制, 相对稳定; 其次, 温室是相对封闭的环境, 害虫和天敌种群动态易于监测 (van Lenteren *et al.*, 1997; van Lenteren, 2000)。载体植物应用于温室害虫防治始于 20 世纪 80 年代, Tacey (1977) 利用番茄饲养丽蚜小蜂防治温室白粉虱, 释放的载体植物系统 9 周内繁殖了 8 000 头寄生蜂, 有效地控制了温室白粉虱的发生。然而该系统使用番茄为载体植物, 温室粉虱作为替代寄主来繁衍天敌, 具有引进害虫的风险。Lambert (2005) 利用毛蕊花作为载体植物, *Ephestia* 卵饲养 *Dicyphus hesperus* (Knight) 成功防治温室白粉虱。目前载体植物系统的构建和应用主要分布在欧美国家, 在其他国家研究较少 (肖英方等, 2012)。近几年来, 我国对载体植物的研究逐渐增多, 除了两篇对国内外载体植物系统研究与应用的综述以外 (肖英方等, 2012; 李先伟等, 2013), 还检索到相关 SCI 文章 6 篇 (Pan *et al.*, 2014; Pan and Liu, 2014; Zhao *et al.*, 2017; Song *et al.*, 2017a, 2017b; Kidane *et al.*, 2018), 中文核心期刊 1 篇 (邓从双等, 2014), 博士论文 4 篇 (Khuhro, 2012; 潘明真, 2015; 王秀爽, 2016; 王圣印, 2016)。

2.1 载体植物系统在防治蚜虫中的应用

载体植物系统在温室蚜虫的生物防治中应用最多, 在现有文献中所占比例为 52.38% (Huang *et al.*, 2011) (表 1), 主要防治棉蚜、桃蚜、马铃薯蚜和茄沟无网蚜。目前记载的防治蚜虫的载体植物系统主要是以麦类和禾本科杂草为载体植物, 以禾谷缢管蚜 *Rhopalosiphum padi* 和麦长管蚜 *Sitobion avenae* 等禾谷类蚜虫 (Cereal aphids) 为替代寄主, 饲养的天敌主要是寄生蜂类 (47 例), 其次是食蚜瘿蚊 *Aphidoletes*

aphidimyza (14 例)。禾谷类植物生长速度快, 易于种植, 且替代寄主蚜虫不危害蔬菜花卉作物, 是较理想的载体植物。然而, 多数禾谷类植物属冷凉作物, 不适合高温环境。夏天在温室内应用时, 寿命较短, 需要经常更换 (Miller and Rebek, 2018), 所以需要进一步搜集更多耐高温的植物用于载体植物的构建中。

2.2 载体植物系统在防治粉虱中的应用

粉虱是温室中非常重要的一类害虫, 主要是烟粉虱 *Bemisia tabaci* 和温室白粉虱。目前文献记载的载体植物系统用于防治粉虱的比例占 27.28%, 饲养的丽蚜小蜂、浅黄恩蚜小蜂 *Encarsia Sophia* 和海氏桨角蚜小蜂 *Eretmocerus hayati* 等寄生性天敌占 42.86%, 其他均为捕食性天敌, 包括捕食螨、捕食蛛和小黑瓢虫等 (Huang *et al.*, 2011) (表 2)。饲养粉虱天敌的载体植物种类较多, 包括茄科、豆科、大戟科、菊科、葫芦科等 16 种植物, 其中烟草和番茄应用最多。防治粉虱的载体植物系统中, 37.14% 的比例利用白粉虱或烟粉虱作为替代寄主或猎物, 因此增加了引进害虫的风险; 部分系统以花粉、花外蜜和粉虱卵作为替代食物。

2.3 载体植物系统在防治蓟马、螨类等害虫中的应用

温室中用于防治蓟马和害螨的载体植物系统有 25 例, 占现有记录的 19.84% (Huang *et al.*, 2011) (表 3)。天敌主要是捕食螨和花蝽; 所用的载体植物主要是一些显花植物, 能够为天敌提供花粉和花外蜜, 从而延长天敌的寿命, 提高控害持久性。

3 存在的问题和展望

载体植物系统模式已经发展 40 余年, 多种系统已商品化生产和大量使用 (Huang *et al.*, 2011), 但是在载体植物系统的构建和使用中仍存在许多问题。在载体植物的选择中, 许多研究仅关注载体植物对替代寄主和天敌昆虫或捕食

螨生物学特性的影响,但是载体植物对天敌昆虫或捕食螨扩散能力、寄生或捕食效率的影响极少研究;此外,关于如何延长载体植物(尤其是禾本科类)在温室环境中的寿命,降低更换频率的研究,目前未见报道。

载体植物系统首先是一个天敌饲养系统,如何提高天敌的质量和饲养效率是非常关键的问题。在载体植物系统构建时,应该系统研究植物-植食性昆虫-天敌三级营养关系,通过载体植物和替代寄主或猎物的筛选和调节,获得质量最好

表 1 用于防治温室蚜虫的载体植物系统
Table 1 List of banker plant system against aphids in greenhouse

载体植物 Banker plants	替代寄主/猎物/食物 Alternative host/prey/food	有益生物 Beneficials	目标害虫 Target pests	栽培作物 Crop	文献 References
高粱 Sorghum	高粱蚜 <i>Melanaphis sacchari</i>	食蚜瘿蚊 <i>Aphidoletes aphidimyza</i>	蚜虫 Aphids	甜椒 Paprika	Abe <i>et al.</i> , 2011
燕麦 Oat	禾谷缢管蚜 <i>Rhopalosiphum padi</i>	科曼尼茧蜂 <i>Aphidius colemani</i>	桃蚜 <i>Myzus persicae</i>	甜椒 Paprika	Andorno and López, 2014
冬小麦 Winter wheat	麦长管蚜 <i>Sitobion avenae</i>	烟蚜茧蜂 <i>Aphidius gifuensis</i>	蚜虫 Aphids	未报道 Not reported	Pan <i>et al.</i> , 2014
阿鲁藤 <i>Araujia</i> sp.	夹竹桃蚜 <i>Aphis nerii</i>	茶足柄瘤蚜茧蜂 <i>Lysiphlebus testaceipes</i>	苜蓿蚜 <i>Aphis craccivora</i>	苜蓿 Alfalfa	Zumoffen <i>et al.</i> , 2016
大麦 Barley	禾谷缢管蚜 <i>Rhopalosiphum padi</i>	科曼尼茧蜂 <i>Aphidius colemani</i>	桃蚜 <i>Myzus persicae</i>	观赏椒 Black pearl pepper	Prado and Frank, 2014
大麦 Barley, 黑麦 Rye, 燕麦 Oat, 小麦 Wheat	禾谷缢管蚜 <i>Rhopalosiphum padi</i>	科曼尼茧蜂 <i>Aphidius colemani</i>	蚜虫 Aphids	未报道 Not reported	Jandricic <i>et al.</i> , 2014
小麦 Wheat	玉米蚜 <i>Rhopalosiphum maidis</i>	龟纹瓢虫 <i>Propylaea Japonica</i>	桃蚜 <i>Myzus persicae</i>	未报道 Not reported	邓从双等, 2014
冬小麦 Winter wheat	麦长管蚜 <i>Sitobion avenae</i>	烟蚜茧蜂 <i>Aphidius gifuensis</i>	桃蚜 <i>Myzus persicae</i> 棉蚜 <i>Aphis gossypii</i>	辣椒 Pepper、 黄瓜 Cucumber	Pan and Liu, 2014
大麦 Barley, 黑麦 Rye, 燕麦 Oat, 小麦 Wheat	禾谷缢管蚜 <i>Rhopalosiphum padi</i>	科曼尼茧蜂 <i>Aphidius colemani</i>	桃蚜 <i>Myzus persicae</i>	观赏椒 Black pearl pepper	McClure and Frank, 2015
大麦 Barley	禾谷缢管蚜 <i>Rhopalosiphum padi</i>	食蚜瘿蚊 <i>Aphidoletes aphidimyza</i>	棉蚜 <i>Aphis gossypii</i>	茄子 Eggplant	Higashida <i>et al.</i> , 2016
牛筋草 Indian goosegrass	狗尾草蚜 <i>Hysteroneura setariae</i>	狭臀瓢虫 <i>Coccinella transversalis</i> 六斑月瓢虫 <i>Menochilus sexmaculata</i>	棉蚜 <i>Aphis gossypii</i>	辣椒 Pepper	Rattanapun, 2017
甘蓝 Cabbage 白菜 Chinese cabbage 油菜 Rape	甘蓝蚜 <i>Brevicoryne brassicae</i>	烟蚜茧蜂 <i>Aphidius gifuensis</i>	蚜虫 Aphids	未报道 Not reported	Song <i>et al.</i> , 2017a
大豆 Soy bean	大豆蚜 <i>Aphis glycines</i>	白足蚜小蜂 <i>Aphelinus albipodus</i>	桃蚜 <i>Myzus persicae</i>	辣椒 Pepper 甜椒 Paprika	Song <i>et al.</i> , 2017b
高粱 Sorghum	高粱蚜 <i>Melanaphis sacchari</i>	食蚜瘿蚊 <i>Aphidoletes aphidimyza</i>	棉蚜 <i>Aphis gossypii</i>	茄子 Eggplant	Higashida <i>et al.</i> , 2017

表 2 用于防治温室粉虱的载体植物系统
Table 2 List of banker plant system against whiteflies in greenhouse

载体植物 Banker plants	替代寄主/猎物/食物 Alternative host/prey/food	有益生物 Beneficials	目标害虫 Target pests	栽培作物 Crop	文献 References
番木瓜 Papaya	白粉虱 <i>Trialeurodes variabilis</i>	丽蚜小蜂 <i>Encarsia sophia</i>	B 型烟粉虱 <i>Bemisia tabaci</i>	番茄 Toamto	Xiao <i>et al.</i> , 2011a
观赏椒 Ornamental pepper	花粉 Pollen	瑞氏钝绥螨 <i>Amblyseius swirskii</i>	烟粉虱 <i>Bemisia tabaci</i>	甜椒 Paprika	Xiao <i>et al.</i> , 2012
烟草 Tobacco	未报道 Not reported	<i>Macrolophus pygmaeus</i>	白粉虱 <i>Trialeurodes variabilis</i>	番茄 Toamto	Bresch <i>et al.</i> , 2014
观赏椒 Pepper	花粉 Pollen	瑞氏钝绥螨 <i>Amblyseius swirskii</i>	粉虱 Whiteflies	未报道 Not reported	Kumar <i>et al.</i> , 2015
罗勒香 Basil	未报道 Not reported	<i>Macrolophus pygmaeus</i>	白粉虱 <i>Trialeurodes variabilis</i>	番茄 Toamto	Parolin <i>et al.</i> , 2015a
马鞭草 Verbena sp.	未报道 Not reported	烟盲蝽 <i>Nesidiocoris tenuis</i>	烟粉虱 <i>Bemisia tabaci</i>	番茄 Toamto	Nakano <i>et al.</i> , 2016
毛蕊花 Mullein	未报道 Not reported	<i>Dicyphus hesperus</i>	白粉虱 <i>Trialeurodes variabilis</i>	番茄 Tomato、 茄 Eggplant、 辣椒 Pepper	Nguyen-Dang <i>et al.</i> , 2016
欧洲耧斗菜 European columbine	忍冬粉虱 <i>Aleyrodes loniceræ</i>	<i>Encarsia tricolor</i>	甘蓝粉虱 <i>Aleyrodes proletella</i>	甘蓝 Cabbage	Laurenz and Meyhöfer, 2017
南瓜 Pumpkin	白粉虱 <i>Trialeurodes vaporariorum</i>				
香瓜 Cucumis melo	烟粉虱 <i>Bemisia tabaci</i>	浅黄恩蚜小蜂 <i>Encarsia sophia</i>	烟粉虱 <i>Bemisia tabaci</i>	番茄 Toamto	Kidane <i>et al.</i> , 2018
蓖麻 Castor bean		海氏桨角蚜小蜂 <i>Eretmocerus hayati</i>			

表 3 用于防治温室蓟马、螨类和其他害虫的载体植物系统
Table 3 List of banker plant system against thrips, spiders and other pests in greenhouse

载体植物 Banker plants	替代寄主/猎物/食物 Alternative host/prey/food	有益生物 Beneficials	目标害虫 Target pests	栽培作物 Crop	文献 References
观赏椒 Black pearl	花粉 Pollen	小花蝽 <i>Orius insidiosus</i>	蓟马 Thrips	观赏草 Ornamental grass	Wong and Frank, 2012
观赏椒 Ornamental pepper	未报道 Not reported	瑞氏钝绥螨 <i>Amblyseius swirskii</i>	西花蓟马 <i>Frankliniella occidentalis</i> 茶黄蓟马 <i>Scirtothrips dorsalis</i>	甜椒 Sweet pepper	Xiao <i>et al.</i> , 2012
观赏椒 Ornamental pepper	花粉 Pollen	小花蝽 <i>Orius insidiosus</i>	蓟马 <i>Frankliniella occidentalis</i>	辣椒 Pepper	Wong and Frank, 2013
辣椒 Pepper	花粉 Pollen	瑞氏钝绥螨 <i>Amblyseius swirskii</i>	蓟马 Thrips	未报道 Not reported	Kumar <i>et al.</i> , 2015
金盏花 Calendula officinalis	花蜜 Extrafloral	东亚小花蝽 <i>Orius sauteri</i>	西花蓟马 <i>Frankliniella occidentalis</i>	番茄 Tomato	Zhao <i>et al.</i> , 2017

续表 3 (Table 3 continued)

载体植物 Banker plants	替代寄主/猎物/食物 Alternative host/prey/food	有益生物 Beneficials	目标害虫 Target pests	栽培作物 Crop	文献 References
玉米 Corn	草地小爪螨 <i>Oligonychus pratensis</i>	捕食蝇 <i>Feltiella acarisuga</i>	二斑叶螨 <i>Tetranychus urticae</i>	豆类 Green bean	Xiao <i>et al.</i> , 2011b
地中海荚蒾 <i>Viburnum tinus</i> , 川椒 <i>Capsicum annuum</i> , 龙爪稷 <i>Eleusine coracana</i>	未报道 Not reported	加州新小绥螨 <i>Amblyseius californicus</i>	二斑叶螨 <i>Tetranychus urticae</i>	月季 Rosa	Parolin <i>et al.</i> , 2013
玫瑰 <i>Rosa sonia</i> , 地中海荚蒾 <i>Viburnum tinus</i>	花粉 Pollen	加州新小绥螨 <i>Amblyseius californicus</i>	二斑叶螨 <i>Tetranychus urticae</i>	菜豆 French bean	Parolin <i>et al.</i> , 2015b
观赏椒 Bell Peppers	未报道 Not reported	瑞氏钝绥螨 <i>Amblyseius swirskii</i>	侧多食跗线螨 <i>Polyphagotarsonemus latus</i>	辣椒 Pepper	Lopez <i>et al.</i> , 2017
芝麻 <i>Sesamum indicum</i> , 黏性旋复花 <i>Dittrichia viscosa</i>	未报道 Not reported	烟盲蝽 <i>Nesidiocoris tenuis</i>	番茄斑潜蝇 <i>Tuta absoluta</i>	番茄 Tomato	Biondi <i>et al.</i> , 2016

的天敌。目前,未见有关如何高效的生产载体植物系统的文章发表。载体植物何时接替代寄主或猎物?接种密度为多少?何时接入天敌?若这些指标得到优化,可以显著提高天敌的饲养效率。

若要发挥载体植物系统的最大功能,除了考虑系统本身三级营养关系之外,还要考虑其与整个靶标环境中的关系,包括目标作物、靶标害虫以及其他生物、非生物因素(陈学新等,2014)。不同害虫(种类、起始密度)、不同的栽培作物均可影响天敌的控害效果。目前,还没有足够的资料为种植者提供准确利用载体植物系统的具体方法,需要研究者进行大量的试验,针对特异害虫和栽培作物形成相应的载体植物系统使用技术规程。

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