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亚洲柑橘木虱的发生与防治研究进展

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摘 要:黄龙病(Citrus Huanglongbing, HLB)是柑橘上一种毁灭性病害,可危害几乎所有的柑橘及其近缘属植物,但目前尚无该病的有效防治方法。亚洲柑橘木虱作为黄龙病重要的传播媒介已成为近年来研究的热点,对亚洲柑橘木虱的防治效果好坏直接关系到黄龙病防控的成败。笔者试图对亚洲柑橘木虱(*Diaphorina citri*)的发生分布、寄主范围、传毒机制、生活史、预测预报及防治方法等方面的研究进展进行总结,同时突出该研究领域的最新研究进展,旨在为更好地防治柑橘黄龙病提供借鉴。

关键词:亚洲柑橘木虱;传毒机制;黄龙病;防治;抗药性

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Advances in researches on the occurrence and control of Asia citrus psyllid

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Abstract: The citrus yellow shoot disease(CYSD), a phloem-limited bacteria [*Candidatus Liberibacter* spp., notably *Ca.* L. Asiaticus (LAS)] disease, is a most destructive and devastating disease of citrus in Asia, Africa, North and South America. All commercially cultivated citrus is susceptible and varieties tolerant to the disease is not yet available. It causes substantial economic losses by reducing fruit production, shortening the lifespan of the tree, but no effective cure has been found. The CYSD-infected trees develop symptoms that include chlorotic leaves, twig dieback, fruit drop, abnormal and small fruits, lower internal fruit quality and eventual death of the whole plant. Three species of *Candidatus Liberibacter* (*Ca. Liberibacter asiaticus*, *Ca. Liberibacter africanus* and *Ca. Liberibacter americanus*) are associated with CYSD And *Ca. Liberibacter asiaticus* is the most important one. CYSD can be transmitted by psyllid and grafting. The Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), is the most efficient vector to CYSD. Although the rate of LAS transmission by *D. citri* individuals is usually low, onset of CYSD occurs following a longer latent period after inoculation, and thus the pathogen can spread widely prior to detection. *D. citri* is attracted to yellow and yellowish-green colors that mimic reflectance spectra of host plants. And it is attracted both to natural host plant odors prevalent in the headspace collection of citrus and to a synthetic terpene mixture modeled on the principal volatiles collected from *M. paniculata*. The upper and lower thresholds for oviposition were estimated to be 16 ℃ and 41.6 ℃, respectively. *D. citri* females are prolific and can develop rapidly, laying up to 800 eggs per lifetime, which are deposited only on young tissue, particularly on newly expanded leaves growing from 1 to 5 days after budbreak. More recent investigations were made by using either conventional polymerase chain reaction (PCR) or real-time PCR(qPCR) to detect Las of psyllid. Worldwide, control of *D. citri* to reduce its role as a vector has been one of three citrical components of CYSD man-

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agement, in addition to planting pathogen-free nursery stocks and removing inoculums by destroying infected trees. It remains to be seen if a number of areas will be explored, notably on *D. citri*-LAS-plant interactions, on host plant resistance to *D. citri*, and on molecular methods of silencing *D. citri* genes to induce mortality or to block its ability to transmit CYSD-causing bacteria. Chemical control is the primary management strategy currently employed, but recently documented decreases in susceptibility of *D. citri* to several insecticides illustrate the need for more sustainable tools. But very little information on insecticidal control againse *D. Citri* was reported in the literature prior to the arrival of CYSD in the Americas in the mid-2000s. Phylogeographic and genetic studies on *D. citri* populations in the Americas indicated that two founding events of *D. citri* probably occurred, one in South America and one in North America. More recent studies on *D. citri's* response to insecticides indicate sensitivity to a number of different insecticide classes, including pyrethroids, organophosphates, carbamates, neonicotinoids, some isect growth regulators (IGRs), horticulturl oil, the lipid synthesis inhibitor spirotetramat, spinetoram, abamectin, and sucrose octanoate. A number of gungal entomopathogens are reported to infect *D. citri* especially under conditions of high humidity, including *Isaria (Paecilomyces) fumosorosea* (Wize), *Lecanicillium lecanii*, and so on. The ectoparasitoid *Tamarixia radiata* (Waterston) (Eulophidae) and the endoparasitoid *Diphorencyrtus aligarbensis* (Shafee, Alam and Argarwal) (Encyrtidae) are generally accepted as the only currently known primary parasitoids of *D. citri*. There is general agreement that the major predators of *D. citri* are lady beetles, lacewings, syrphids, and spiders. However, the relative importance of each group is less certain due in part to the difficulty in evaluating their individual contributions to mortality. Hundreds of thousands of trees in Florida that probably were infected before the management program was implemented were removed from groves. The extent to which the three-tiered management problem negates incidence and spread of the disease may depend largely on levels of inoculum within and around a grove. Within less than 7 years of the discovery of CYSD in Florida, most growers found the three-tiered program too expensive, were reluctant to remove infected trees that were productive and consequently abandoned efforts to remove trees unless they were non-productive. More recently, a number of growers have implemented three nutritional programs hoping to sustain the producticity of infected trees, but there has been no published research supporting this idea. Advances in these and other research areas may depend greatly on a better understanding of basic *D. citri* biology and vector-pathogen-host plant interactions at the molecular, cellular, and community levels. Here, we present an updated review of *D. citri* and CYSD with an emphasis on the problem in the world. Currently considering *D. citri,* the world's most serious disease of citrus, is transmitting quickly, it has been a hot topic of citrus researches. In this paper, the distribution, host plants, mechanism of transimission, life cycle, forecasting and prevention methods were summarized. This review will lay a sound foundation for better control of CYSD.

Key words: Asian citrus psyllid; Virus-Transimission Mechanism; Huanglongbing; Control; Insecticide resistance

黄龙病（Citrus Huanglongbing, HLB）是一种系统侵染的检疫性细菌病害，可引起叶片黄化、果实商品价值降低，严重时可导致树体死亡。目前在亚洲、非洲、南北美洲、欧洲等近50个国家和地区均有分布，且其发生范围仍在扩大，已成为威胁世界柑橘产业发展的头号“杀手”[1-3]。虽然各国研究人员对黄龙病的防控方法和技术开展了大量研究，但利用无病毒苗木、铲除病树和防控木虱仍是目前最为有效的防治手段。基于HLB早期侵染难于监测及其迅速扩展性，防控木虱成为阻断黄龙病发生的重要措施。

虽然亚洲柑橘木虱（*Diaphorina citri*）、非洲柑橘木虱（*Trioza erytreae*）和柚喀木虱（*Cacopsylla citrisuga*）都可以传播黄龙病，但以亚洲柑橘木虱的分布范围最广，危害最为严重，是黄龙病最为重要的传播媒介。为此笔者从寄主范围、传毒机制、发生特点、防治方法等方面对亚洲柑橘木虱的研究进展作

一综述，旨在为更好地防治黄龙病提供借鉴。

1　发生分布与危害

亚洲柑橘木虱最早于1907年在台湾有记载[4]，也有人认为起源于印度[5-6]，后扩散到世界各地。目前我国广东、广西、福建、台湾、江西、四川、湖南、贵州、浙江等地皆有亚洲柑橘木虱分布。20世纪40年代在巴西首次发现了亚洲柑橘木虱，随后于90年代扩侵到美国佛罗里达州。目前在美国各柑橘生产州皆有分布[7-10]。亚洲柑橘木虱属于耐热型，27~32 ℃均可生存。其成虫喜在嫩梢上产卵，若虫和成虫在嫩叶、嫩梢上取食，引起叶片干枯，其排泄物还可诱发煤烟病，影响新梢生长。

2　寄主植物

亚洲柑橘木虱寄主广泛，可取食长春花（*Murraya paniculata*）和几乎所有的柑橘品种[11-12]，但不能取食箭叶橙(*Citrus hystrix*)和枸橘(*Poncirus trifoliata*)、及柑橘近缘种白柿（*Casimiroa edulis*）[13]。此外，柑橘木虱取食具有偏好性，Jatti khatti 粗柠檬 (*Citrus jambhiri* Lushington) 和 Kagzi lime 莱檬（*Citrus aurantifolia* Christm）上亚洲柑橘木虱的种群数量少于甜橙(*Citrus sinensis*)，且枳对柑橘木虱的产卵具有显著的抑制作用[14- 15]。此外，'Troyer citrange' 'Swingle citrumelo' 和 'Limonia acidissima' 是对柑橘木虱的高度耐受品种，可用于HLB防控[15]。

3　传毒机制

早期研究认为，亚洲柑橘木虱获毒时间为25 min~24 h，传毒时间为15 min~7 h[16-17]。于病树上吸食5周以后，其若虫带毒率为60%~100%，成虫能达到40%。目前的研究显示，亚洲柑橘木虱卵、1~3龄若虫不会传染，其2~3龄若虫可获毒，4~5龄若虫和成虫可以传病，老龄若虫携带的病原菌会终身带菌[18]。黄龙病病菌能在木虱体内增殖，且可在成虫交配过程中相互传染[18-19]。亚洲柑橘木虱的唾液腺、前肠滤室、肠道、淋巴、肌肉以及脂肪等组织中可以观察到黄龙病菌[20-21]。HLB病株能产生一种特殊的嗅觉信号分子，从而较健康植株更能吸引亚洲柑橘木虱取食，但由于HLB病树不适合柑橘木虱生长，因此亚洲柑橘木虱转而取食周边其他健康老熟叶片，从而造成HLB扩散[22-23]。

4　生活史

雌性亚洲柑橘木虱1 a（年）可发生11~14代，田间世代重叠明显。雌性木虱在交配后1 d即可产卵[24]，一生可以产800粒卵，但仅产于柑橘幼嫩组织尤其是嫩叶上。卵2~4 d孵化，5个幼龄期11~15 d，整个生活史为15~47 d，成虫停息时尾部翘起，与停息面成45°角[25]。雌雄柑橘木虱在嫩叶上交配时间为20~100 min。雌性柑橘木虱一生中需多次交配来维持最大化的产卵量，但受到雄性数量的影响。亚洲柑橘木虱最佳生长温度为25~28 ℃[25]，最佳产卵温度为28~29.6 ℃，最高及最低产卵阈值温度分别为41.6 ℃和16 ℃[26]。

5　柑橘木虱发生特点与流行学

亚洲柑橘木虱传播黄龙病，传病频率高、速度快，可终身传播黄龙病病菌，但自主飞行能力较差。黄龙病的流行病学调查结果表明，亚洲柑橘木虱在柑橘园的扩散距离为25~50 m[27]，在岛与岛之间的最大的扩散距离为470 km[28]。免疫标记技术研究表明，亚洲柑橘木虱在3 d、4 d和12 d内可以分别移动100 m、400 m和2 km[29-31]。通常春季嫩叶期亚洲柑橘木虱的迁移能力最强[32-33]，但在佛罗里达州的研究表明，春夏季节亚洲柑橘木虱在田间的迁移能力强，在较冷的月份（9月至次年3月）显著下降。亚洲柑橘木虱可以越过道路、休耕地等潜在的地理障碍进行扩散，风向和亚洲柑橘木虱的扩散没有直接的关系[33]。此外，研究表明，大约32%腹部为绿和蓝色的亚洲柑橘木虱具有长期飞行能力，可以持续飞行60 s，然而只有不到5%腹部为灰和棕色的柑橘木虱有如此强的飞行能力。柑橘木虱的飞行能力与其性别及翅的大小无关[34]。

6　发生预测

Monzo等[35]连续4 a在245个监测点进行了5种亚洲柑橘木虱抽样方法的精确度、敏感度及效率评估。结果表明，当亚洲柑橘木虱的种群密度为适中或较高时，枝干敲打法最为高效；当种群密度低时，直接观察法的监测效率最高。目前根据相关物种分布建立的MaxEnt和Multi-Model Framework模型已成功预测了黄龙病，以及亚洲柑橘木虱在非洲、拉丁美洲、北澳大利亚等地区可能的分布区域。此

外，通过应用PBDM(Physiologically Based Demographic Model)进行文献数据总结，可以预测亚洲柑橘木虱的地理分布、相对密度以及柑橘的相对产量等，从而为制定防控策略提供重要的参考依据[36]。研究显示，大气气压、温度、湿度等非生物因素能影响亚洲柑橘木虱在柑橘之间的分布，木虱分散随温度及大气压力改变而变化，但不受湿度变化影响，从而建立了亚洲柑橘木虱受非生物因素影响的扩展模型[37]。

7 防治方法

7.1 化学防治

拟除虫菊酯、有机磷、氨基甲酸酯、新烟碱、昆虫生长调节剂（IGRs）、矿物油、螺虫乙酯、乙基多、阿维菌素、蔗糖辛酸酯等杀虫剂都可用于防治柑橘木虱[38-52]。其中，除虫菊酯、有机磷和新烟碱类等广谱性杀虫剂对柑橘木虱成虫的防效最好，矿物油和IGRs更适于防治亚洲柑橘木虱的卵和若虫[53]。应用化学药剂对越冬亚洲柑橘木虱成虫进行防治可大大降低其种群数量[48]，并可最小限度地影响亚洲柑橘木虱的天敌[48]。此外，广谱性吡虫啉等对瓢虫等天敌比较友好，但除除虫脲外，大多数杀虫剂对蜜蜂有杀伤作用[54]。

由于柑橘幼嫩组织在接种HLB后15 d才具有传毒的菌量，因此在柑橘叶幼嫩时期使用杀虫剂可减少约75%带毒的亚洲柑橘木虱的发生量，进而减少全年杀虫剂的使用。此外，涕灭威可有效清除土壤中亚洲柑橘木虱蛹，且效果持久。氟啶虫胺腈（sulfoxaflor）、氟吡哆醛、Flupyrdifurone等也可能是行之有效的可用于亚洲柑橘木虱的防控药剂[55-56]。

随着杀虫剂的大量使用，杀虫剂抗性已成为柑橘生产面临的重要问题。在佛罗里达等地，亚洲柑橘木虱对氯吡虫胺、甲氰菊酯等杀虫剂的耐药性继续增强[50]。此外，柑橘离体叶法，以及生物测定瓶已被用于柑橘木虱杀虫剂的快速筛选研究[57-58]。亚洲柑橘木虱卵、若虫、成虫转录组确定不同生命阶段的杀虫剂敏感的相关基因，也可大大帮助未来杀虫剂使用[59]。

7.2 物理、性诱和栽培措施防治

亚洲柑橘木虱喜欢黄色与淡黄色反射光谱的寄主[60-61]并将卵产于寄主的幼嫩组织[62]。Sétamou等[63]研究表明，黄色诱虫粘板对亚洲柑橘木虱的诱捕效果最好，红色和绿色诱捕器效果次之，蓝色和白色诱虫粘板的效果最差。性引诱方面，已交配过的雄性亚洲柑橘木虱比未交配过的雄性更具有吸引力[64]。柑橘品种上讲，莱檬上诱捕的亚洲柑橘木虱数量多于甜橙和葡萄柚[63]，对其引诱剂的开发有一定的参考作用。

7.3 生物防治

7.3.1 真菌 现已报道亚洲柑橘木虱的病原真菌包括玫烟色拟青霉 *Isaria* (Paecilomyces) *fumosorosea* (Wize)、蜡蚧轮枝菌 *Lecanicillium lecanii*[65-69]、球孢白僵菌 *Beauveria bassiana* (Bals.) 和檬形被毛孢等 *Hirsutella citriformis*[70-72]。其中，*I. fumosorosea* 已被开发作为防治亚洲柑橘木虱的生物农药[73]。田间亚洲柑橘木虱中 *H. citriformis* 的发生率较高[74]，且美国佛罗里达州在阴雨天气之后应用 *H. citriformis* 的孢子和菌丝混合物作为生防制剂防治亚洲柑橘木虱已获得了成功，但因为其孢子产生率低等原因，难以工厂化大规模生产[75-76]。Ausique等[77]从17种真菌中筛选出 *Isaria fumosorosea* ESALQ-1269 和 *Beauveria bassiana* ESALQ-PL63，在田间试验中其对亚洲柑橘木虱成虫的致死率高达83.5%和80.6%。

7.3.2 寄生蜂 柑橘木虱啮小蜂 *Tamarixia radiate* (Waterston) 和阿里食虱跳小蜂 *Diaphborencyrtus aligarhensis* (Shafee，Alam and Argarwal)是2种目前被普遍认可的亚洲柑橘木虱寄生蜂。*T. radiate* 是专性内寄生蜂，主要寄生于亚洲柑橘木虱的3~5龄若虫，每头雌蜂可寄生柑橘木虱若虫500只[78]。*T. radiate* 已被成功引进到留尼旺岛、中国台湾、毛里求斯、菲律宾、沙特阿拉伯、东爪哇、印度尼西亚、瓜德罗普、佛罗里达等地来防治亚洲柑橘木虱[79-80]。*D. aligarhensis* 在中国、菲律宾、越南、留尼旺岛及沙特阿拉伯皆有报道[81]。*T. radiate* 和 *D. aligarhensis* 可在田间混合发生，但是 *T. radiate* 占主导地位，应用范围更广[75]。*T. radiate* 的生长周期也比 *D. aligarhensis* 短4 d左右[82-83]。因此，*T. radiate* 是寄生蜂防控柑橘木虱的第一选择。目前通过改进饲养密度、选择最佳寄主等方法，极大地提高了 *T. radiate* 产量[56]。*D. aligarhensis* 也因其不影响的寄生特点，可被用来加强亚洲柑橘木虱的防控。近年来德克萨斯州通过释放 *T. radiata* 大大降低了亚洲柑橘木虱的种群数量[84]。

7.3.3 捕食性天敌 亚洲柑橘木虱主要捕食性天敌

为瓢虫、草蛉、蜘蛛和蓟马等。Florida的调查表明[85]，异色瓢虫*Harmonia axyridis* (Pallas)、楔斑溜瓢虫*Olla v-nigrum*(Mulsant)及奇氏光源瓢虫*Exochomus childreni* (Mulsant)是夏末秋初亚洲柑橘木虱最主要的捕食性天敌。我国正式记载的捕食亚洲柑橘木虱的瓢虫有近20种，包括龟纹瓢虫*Propylea japonica*、七星瓢虫*Coccinella septempunctata*等。捕食亚洲柑橘木虱的蓟马包括带翅虱管蓟马*Aleurodothrips fasciapennis*、长角六点蓟马*Scolothrips sexmaculatus*等。此外，喜食鳞翅目卵的亚洲蟑螂*Blattella asahinai* (Mizukubo)[86]、斯氏钝绥螨*Amblyseius swirskii* (Acari: Phytoseiidae)[87]和新报道的长腿虻*Diptera: Dolichopodidae*[88]也极具防控亚洲柑橘木虱的潜力。

7.4　新的防治手段

基因沉默是一种对环境友好的亚洲柑橘木虱控制策略[89]。dsRNA可以通过喂食的方式进入亚洲柑橘木虱体内，从而干扰木虱的生长发育进程，且基因沉默的效果与dsRNA的饲喂量呈正相关[90]。目前通过dsRNA技术可导致亚洲柑橘木虱体重减少、死亡率上升[91]，同时也能提高亚洲柑橘木虱对农药的敏感性[92]。此外，通过喂食由柑橘衰退病毒构建的*Awd*沉默载体，可抑制柑橘木虱幼虫中*Awd*基因的表达量，从而导致成虫畸形、死亡率增加[93]。

8　防控技术思路与展望

目前，防控亚洲柑橘木虱仍是阻止黄龙病蔓延的重要手段。亚洲柑橘木虱可高效传播柑橘黄龙病，其防控研究仍是全球关注的焦点与难点。随着全球气候变暖，亚洲柑橘木虱在我国北移加剧，且由于长时间大量、单一使用化学农药，造成亚洲柑橘木虱抗药性逐渐增强，我国黄龙病防控形势依然严峻。近年来，科技工作者拓宽了思路加强对亚洲柑橘木虱的防控：1）加强亚洲柑橘木虱防控药剂筛选及新药剂研发，提高药剂的防治效果及多样性，便于交替使用，延缓亚洲柑橘木虱抗药性产生；2）研发适合无人机喷药技术的药剂种类及使用浓度，提高对亚洲柑橘木虱防效；3）加强对柑橘木虱的监控，研发智能识别亚洲柑橘木虱的仪器，精确预测预报亚洲柑橘木虱的发生发展，并在国内设立阻截带防止其进一步扩展；4）结合柑橘控梢措施，完成对亚洲柑橘木虱的防控；5）逐渐应用转基因、基因沉默等较新的研究技术，为柑橘木虱防控提供新的思路。

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