



斯氏钝绥螨生物生态学特性及 生物防治研究进展*

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摘 要 斯氏钝绥螨 *Amblyseius swirskii* 作为一种重要的商品化天敌, 可有效控制害螨、粉虱和蓟马等多种小型有害生物, 已成为害虫综合管理体系的核心生物防治天敌。本文系统梳理了斯氏钝绥螨的研究进展, 重点从其形态学鉴别特征、环境适应性、种间互作关系、人工繁育技术和生物防治及应用等方面进行综述, 并阐述了当前研究存在的突出问题, 对今后的研究方向进行了展望。

关键词 斯氏钝绥螨; 天敌; 植绥螨; 生物防治

Progress in research on the biology, ecology, and application, of *Amblyseius swirskii* for biological control

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Abstract The predatory mite *Amblyseius swirskii* is a commercially important biological control agent for various small pests, such as pest mites, whiteflies and thrips, and which has become a crucial biocontrol agent in integrated pest management systems. This paper summarizes progress in research on *A. swirskii*, focusing on morphological identification, environmental adaptability, interspecific interactions, artificial rearing, and biological control applications. Future prospects for research on, and the application of, *A. swirskii* are discussed.

Key words *Amblyseius swirskii*; natural enemy; phytoseiidae; biological control

斯氏钝绥螨 *Amblyseius swirskii* 隶属于蛛形纲 Arachnida、蜱螨亚纲 Acari、寄螨目 Parasitiformes、中气门亚目 Mesostigmata、植绥螨科 Phytoseiidae。其异名包括斯氏小盲绥螨

Typhlodromips swirskii、*Amblyseius capsicum*、*Amblyseius enab* 及 *Amblyseius rykei* 等(吴伟南和方小端, 2021; Tixier *et al.*, 2022)。该物种起源于东部地中海区域, 现分布于阿根廷、阿塞

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拜疆、埃及、巴勒斯坦、贝宁、布隆迪、佛得角、刚果民主共和国、格鲁吉亚、古巴、加纳、津巴布韦、肯尼亚、留尼汪岛（法国）、马拉维、美国、尼日利亚、沙特阿拉伯、塞内加尔、斯洛文尼亚、坦桑尼亚、土耳其、西班牙、叙利亚、也门、以色列、意大利和扎伊尔等多个国家和地区（吴伟南和方小端，2021；Tixier *et al.*, 2022）。

斯氏钝绥螨寄主范围广，可栖息于 48 科 92 属的 132 种植物，涵盖蔷薇科 Rosaceae、芸香科 Rutaceae、茄科 Solanaceae、豆科 Leguminosae、菊科 Compositae、锦葵科 Malvaceae 等（Tixier *et al.*, 2022）。自 2005 年实现商业化生产以来，该捕食螨已在全球 50 多个国家成功应用于多种害虫和害螨的增强型生物防治（Augmentative biological control）（Calvo *et al.*, 2015）。作为我国引进的重要天敌资源，斯氏钝绥螨经本土化繁育技术优化后，已在设施农业中应用，并显著提升了对害螨、粉虱和蓟马等小型节肢有害生物的防控效能。

近年来，围绕斯氏钝绥螨的基础与应用研究取得显著进展。在基础生物生态学方面，研究涵盖其形态特征、环境适应性和种间互作关系等关键领域；在应用技术方面，则重点突破了人工规模化繁育技术及生物防治应用体系，推动了其产业化进程。

1 斯氏钝绥螨的形态学特征

斯氏钝绥螨包括卵、幼螨、第一若螨、第二若螨和成螨 5 个发育阶段，各阶段形态特征如下：

卵：呈椭圆形，淡白色，体长约 150 μm 。雌成螨偏好将卵产于植物叶背的螨窝（Domatia）内或邻近螨窝的表皮毛（Trichomes）上。

幼螨：具 3 对足，体色半透明至淡白色，体长约 160 μm ，背板两块，腹部轮廓近圆形，移动缓慢。

若螨：具 4 对足，体色随龄期加深，第二若螨的腹部呈椭圆形，形态近似成螨。

雌成螨：背板长约 338（326-352） μm ，宽约 205（202-208） μm ，表面光滑，仅 S2 前缘具稀疏侧纹。背刚毛共 19 对，其中较长的刚毛 Z5 >

s4 > Z4 > j3 > j1，Z4 和 Z5 具微刺，其余刚毛光滑。胸骨盾光滑，有少量侧纹。腹肛板近似五边形，在肛前孔水平处略收缩，前缘微凸。螯肢较小，动趾具 3 齿，定趾具 9-10 齿，具钳齿毛 1 根。气门沟延伸至超过 j1 刚毛基部的水平位置。受精囊呈花萼杯状，囊颈室结节状。足 IV 膝关节和基跗节各具巨毛 1 根（Zannou *et al.*, 2007）。

雄成螨：背板长约 258 μm ，宽约 190 μm ，背刚毛 19 对，仅 Z4 和 Z5 具微刺。腹肛板近似三角形，肛前孔前缘具网纹。气门沟延伸至 j1 和 j3 之间。导精趾 L 形，轴杠长 19 μm （Zannou *et al.*, 2007）。

2 斯氏钝绥螨的环境适应性研究

斯氏钝绥螨的生物学特性及控害能力受多种环境因子调控。国内外研究表明，温度、杀虫剂及湿度等关键因子通过影响发育速率、繁殖效率和捕食行为，显著影响斯氏钝绥螨的生态适应性。

2.1 温度适应性

温度对斯氏钝绥螨的生长发育和繁殖具有显著影响。基于线性模型分析，斯氏钝绥螨卵、幼螨、第一若螨和第二若螨的发育起点温度分别为 11.45、3.54、9.45 和 9.29 $^{\circ}\text{C}$ ，相应的有效积温依次为 25.29、31.31、33.21 和 33.73 日·度（Farazmand *et al.*, 2020）。斯氏钝绥螨在 15-36 $^{\circ}\text{C}$ 的温度范围内均能完成发育并进行繁殖，且在此范围内，随温度升高，其发育历期和平均世代周期（ T ）缩短，内禀增长率（ r ）和周限增长率（ λ ）增加（陈霞等，2011a, 2011b）。该螨发育和繁殖的最适温度范围为 22-32 $^{\circ}\text{C}$ （Lee and Gillespie, 2011；Al-Azzazy and Alhewairini, 2020；Farazmand and Amir-Maafi, 2020；Rahimi *et al.*, 2022）。然而，极端温度会显著降低斯氏钝绥螨的生态适应性。例如，在 2 $^{\circ}\text{C}$ 低温胁迫 2 d 后，雌成螨的存活率仅为 55.28%（Krutiakova and Limar, 2020）；42 $^{\circ}\text{C}$ 高温胁迫 5 h 后，斯氏钝绥螨卵的孵化率仅为 42%（宋文斌，2021）。

斯氏钝绥螨的捕食效能（ a/T_h ）表现出明显

的温度依赖性。在一定温度范围内,其捕食能力随温度的升高而增强,并在适宜温度条件下达到峰值,之后随温度进一步升高而减弱。例如,在 16-32 °C 温度范围内,斯氏钝绥螨对朱砂叶螨 *Tetranychus cinnabarinus* 第一若螨的捕食效能在 28 °C 达到峰值 9.840,随后降低(王利平等, 2011)。在 15-35 °C 温度范围内,斯氏钝绥螨雌成螨对西花蓟马 *Frankliniella occidentalis* 第一若虫的捕食效能在 30 °C 达到峰值 18.146(罗春萍等, 2018)。此外,其捕食功能反应类型也随温度发生变化。例如,在 25 °C 条件下,斯氏钝绥螨对二斑叶螨 *Tetranychus urticae* 卵的捕食反应为 Holling III 型,而在 30 和 35 °C 时则转变为 Holling II 型(Rafizadeh Afshar and Latifi, 2017)。上述结果表明,斯氏钝绥螨捕食的适宜温度与其生长发育的适宜温度高度重叠。田间应用时,若环境温度过高或过低,都将削弱斯氏钝绥螨的控害能力。

2.2 农药胁迫效应

化学防治是控制害虫的关键策略之一。然而,化学药剂不仅作用于靶标害虫,还会对其天敌的生存、发育、繁殖及捕食行为产生负面效应,从而削弱天敌的控害能力。研究表明,在田间推荐浓度下,多种农药显著抑制斯氏钝绥螨的存活。例如,经杀虫剂阿维菌素和哒螨灵处理 120 h 后,斯氏钝绥螨各螨态的死亡率范围为 21.66%-95.00%。同时,这两种药剂处理下雌成螨的日均产卵量(阿维菌素: 1.24 粒;哒螨灵: 0.35 粒)均显著低于对照组(2.65 粒)(Döker and Kazak, 2019)。植物源杀螨剂 Cimax® 和 EPA-90® 对斯氏钝绥螨成螨的致死率分别达到 95% 和 80% (48 h)(Cua-Basulto *et al.*, 2023)。杀菌剂乙基多杀菌素、多杀菌素和丙氧喹啉对斯氏钝绥螨卵、幼螨和雌成螨的致死率分别在 43.34% (72 h)、96.66% (192 h) 和 90.00% (120 h) 以上(Döker *et al.*, 2024)。即使在亚致死浓度下,部分化学药剂仍对斯氏钝绥螨表现出毒性。例如,LC₁₀、LC₂₀ 和 LC₃₀ 的联苯肼酯(Havasi *et al.*, 2021)、克螨特(Alinejad *et al.*, 2020)、啉虫脒(Shahbaz *et al.*, 2019)、啉虫醚(Alinejad

et al., 2014), LC₁₀ 和 LC₃₀ 的丁氟螨酯(Havasi and Kheradmand, 2024)以及 LC₅、LC₁₅ 和 LC₂₅ 的 Eforia(Mousavi *et al.*, 2023b)对斯氏钝绥螨的发育、繁殖或种群参数均存在负面影响。因此,这些药剂在与斯氏钝绥螨的联合应用时需十分谨慎。

然而,在田间推荐浓度下,某些化学农药对斯氏钝绥螨无明显毒害作用。例如,喷施甲氧虫酰肼和氟啶虫酰胺 30 d 后,斯氏钝绥螨的种群数量与对照不存在显著差异(Colomer *et al.*, 2011)。此外,LC₁₀、LC₂₀ 和 LC₃₀ 的螺螨酯(Alinejad *et al.*, 2016)和 Envidor(Mousavi *et al.*, 2023a),以及 LC₃₀ 和 LC₅₀ 的迷迭香 *Rosmarinus officinalis*(Shirvani *et al.*, 2023)、薄荷 *Mentha piperita* 和月桂 *Laurus nobilis* 精油(Shirvani *et al.*, 2024)均未对斯氏钝绥螨的存活、发育、繁殖造成显著影响,这些药剂具备与斯氏钝绥螨联合应用防控靶标害虫的潜力。值得注意的是,个别农药在亚致死浓度下甚至对斯氏钝绥螨种群产生了积极效应。例如,LC₂₅ 的苦参碱可提高斯氏钝绥螨的净繁殖率(R_0)和内禀增长率(Kordestani *et al.*, 2022)。

2.3 其他环境因素

在自然或人工环境中,天敌可能会因猎物短期匮乏而经历饥饿。Elsawi 和 Abou-Awad (1992)的研究发现,饥饿显著影响了斯氏钝绥螨的寿命。Ji 等(2013)的研究则报道了斯氏钝绥螨具有较强的耐饥性,其若螨和雌成螨在饥饿条件下的存活时间显著长于江原钝绥螨 *Amblyseius eharai* 和具瘤神蕊螨 *Agistemus exsertus*。此外,相对湿度和水分供应也是影响斯氏钝绥螨种群动态的重要因子。当环境相对湿度低于 53% 时,斯氏钝绥螨卵的孵化率降低、未成熟期和产卵前期延长,但其若螨和成螨可以取食猎物或植物汁液以补充水分(San *et al.*, 2021)。

3 斯氏钝绥螨与其他物种的种间互作关系研究

斯氏钝绥螨的生态位构建涉及多维生物互

作网络, 其与寄主植物、靶标猎物、其他天敌及昆虫病原真菌的互作模式直接影响生物防治效能。

3.1 寄主植物适应性

斯氏钝绥螨对不同寄主植物表现出选择偏好。Razzak 等 (2022) 发现, 在菜豆 *Phaseolus vulgaris*、黄瓜 *Cucumis sativus*、黄南瓜 *Cucurbita pepo*、茄子 *Solanum melongena*、墨西哥辣椒 *Capsicum annuum* 和番茄 *Solanum lycopersicum* 6 种作物中, 茄子上的斯氏钝绥螨种群密度最高。寄主植物的物候期也显著影响斯氏钝绥螨的分布格局。在辣椒开花前, 斯氏钝绥螨的种群数量与叶片上的螨窝数量呈正相关, 而开花后则与花粉类型相关 (Avery *et al.*, 2014)。此外, 在空间分布格局上, 斯氏钝绥螨偏好寄主植物的中下部位置, 多聚集于叶背皱褶及叶基等微生境 (Elshazly, 2022)。

寄主植物表皮毛对斯氏钝绥螨的运动能力和生长发育存在影响。Buitenhuis 等 (2014) 发现, 斯氏钝绥螨在光滑塑料片上运动速度最快, 而在具有表皮毛的玫瑰 *Rosa kordesii*、秋菊 *Dendranthema grandiflora*、非洲菊 *Gerbera jamesonii* 和番茄叶片上运动较慢。Fahim 和 El-Saiedy (2021) 也发现, 斯氏钝绥螨在表皮毛较短的 029 草莓品系上表现出更高的净繁殖率、内禀增长率、周限增长率, 以及较短的世代周期。

寄主植物的次生代谢物质限制了斯氏钝绥螨的定殖。Paspali 等 (2021) 研究发现, 番茄叶片分泌的酰基糖 (Acylsugars) 显著降低斯氏钝绥螨成螨的存活率, 并导致了雌成螨的回避行为。Pandey 等 (2023) 发现, 尽管含有高酰基糖的番茄品系能有效抑制粉虱种群, 却完全遏制了斯氏钝绥螨的定殖。因此, 在作物抗虫育种中需权衡害虫防治与天敌保育的关系。

3.2 似然竞争

似然竞争 (Apparent competition) 指两个物种通过共同捕食者而产生的竞争 (Holt and Bonsall, 2017)。斯氏钝绥螨介导了靶标猎物间的似然竞争。例如, 在烟粉虱 *Bemisia tabaci* 与

二斑叶螨共存系统中, 斯氏钝绥螨优先捕食二斑叶螨, 促使优势猎物种群由二斑叶螨向烟粉虱转变 (郑全明, 2021)。杨益 (2023) 进一步的试验也发现, 斯氏钝绥螨对西花蓟马的捕食效能强于烟粉虱, 从而在两种猎物共存时烟粉虱更容易成为优势种群。此外, 这种由斯氏钝绥螨所介导的似然竞争也有助于提升其对靶标猎物的控制效能。Messelink 等 (2008) 的研究发现, 当西花蓟马和温室白粉虱 *Trialeurodes vaporariorum* 共存时, 斯氏钝绥螨的种群数量是单一温室白粉虱存在时的 15 倍, 西花蓟马的存在显著提升了斯氏钝绥螨对温室白粉虱的控制潜能。

3.3 集团内捕食作用

集团内捕食作用 (Intraguild predation, IGP) 广泛存在于天敌群落, 并在害虫生物防治实践中具有重要意义。斯氏钝绥螨与多种捕食螨之间存在 IGP, 包括具瘤神蕊螨 (Rasmy *et al.*, 2004)、东方钝绥螨 *Amblyseius orientalis* (郭颖伟, 2014)、*Euseius concordis* (Cavalcante *et al.*, 2017)、*Euseius scutalis* (Rasmy *et al.*, 2004)、*Euseius stipulatus* (Warburg *et al.*, 2019)、巴氏新小绥螨 *Neoseiulus barkeri* (Bohloolzadeh *et al.*, 2018)、加州新小绥螨 *Neoseiulus californicus* (郭颖伟, 2014)、黄瓜新小绥螨 *Neoseiulus cucumeris* (李玉晶等, 2022)、智利小植绥螨 *Phytoseiulus persimilis* (Haghani *et al.*, 2015), 并表现出 IGP 优势, 其为集团内捕食者。然而, 当其与圆果大赤螨 *Anystis baccarum* 相互作用时, 斯氏钝绥螨为集团内猎物 (Saito *et al.*, 2023)。此外, 斯氏钝绥螨与其他捕食性天敌之间也存在 IGP。烟盲螨 *Nesidiocoris tenuis*、*Macrolophus pygmaeus* (Bouagga *et al.*, 2018)、*Orius insidiosus* (Lorenzo *et al.*, 2021) 和 *Orius laevigatus* (Mendoza *et al.*, 2024) 均可捕食斯氏钝绥螨的低龄螨态。然而, 斯氏钝绥螨与食蚜瘿蚊 *Aphidoletes aphidimyza*、大灰优食蚜蝇 *Eupeodes corollae*、宽尾细腹食蚜蝇 *Sphaerophoria rueppellii* 之间为双向性 IGP (Retsi *et al.*, 2023)。

食物的存在能显著降低斯氏钝绥螨与其它天敌的 IGP 水平。例如, 当二斑叶螨和玉米 *Zea*

mays 花粉存在时, 斯氏钝绥螨对巴氏新小绥螨和东方钝绥螨的 IGP 水平显著降低 (Maleknia *et al.*, 2016)。类似地, 当系统中添加截形叶螨 *Tetranychus truncatus*、烟粉虱、温室白粉虱或西花蓟马时, 斯氏钝绥螨和巴氏新小绥螨的 IGP 水平降低 (尹云飞, 2016)。此外, 当地中海粉螟 *Ephestia kuehniella* 存在时, 圆果大赤螨对斯氏钝绥螨的 IGP 水平显著下降, 其死亡率与仅存在斯氏钝绥螨时无显著差异 (Saito *et al.*, 2023)。

3.4 螨菌互作

昆虫病原真菌寄主范围广, 除侵染靶标害虫外, 还对天敌等非靶标生物具有潜在的致死和亚致死风险。例如, 球孢白僵菌 *Beauveria bassiana* F 和 J.B. 菌株处理 7 d 后, 斯氏钝绥螨成螨的死亡率分别达到 34.37% 和 40.62% (Seiedy *et al.*, 2015)。球孢白僵菌 GH 菌株处理下, 斯氏钝绥螨成螨的繁殖率降低 (Midthassel *et al.*, 2016)。斯氏钝绥螨在取食经球孢白僵菌 DEBI008 菌株处理后的温室白粉虱时, 表现出更长的搜寻时间和取食时间, 同时捕食率也有所下降 (Seiedy *et al.*, 2015)。然而, 某些昆虫病原真菌菌株对斯氏钝绥螨的毒性较低, 两者具有协同应用防控靶标害虫的潜能。例如, 腊蚧轮枝菌 *Verticillium lecanii* V3450 菌株对斯氏钝绥螨相对安全, 两者具有协同控制榕母管蓟马 *Gynaikothrips uzeli* 为害的潜能 (余德亿等, 2015)。

4 斯氏钝绥螨的繁育技术研究

斯氏钝绥螨已形成由自然猎物、花粉、替代猎物及人工饲料繁育的技术体系 (表 1), 其营养生态适应性研究为生物防治应用提供了重要支撑。

4.1 自然猎物繁育法

斯氏钝绥螨能以多种自然猎物为食, 完成其生长、发育和繁殖, 主要包括害螨、粉虱和蓟马等。研究显示, 斯氏钝绥螨能以瘿螨 *Aceria mangiferae*、番茄刺皮瘿螨 *Aculops lycopersici*、

Cisaberoptus kenya 和 *Metaculus mangiferae* 为食完成生长发育和繁殖 (Abou-Awad *et al.*, 2010; Park *et al.*, 2011)。此外, 研究表明, 斯氏钝绥螨取食叶螨 *Eotetranychus frosti* 时内禀增长率 (0.18) 和周限增长率 (1.19) 均高于其取食细须螨 *Cenopalpus irani* 时的相应值 (0.14 和 1.15)。尽管如此, 这两种害螨均能作为斯氏钝绥螨繁育的自然猎物 (Bazgir *et al.*, 2018)。当以柑橘全爪螨 *Panonychus citri* 为食时, 斯氏钝绥螨表现出较短的发育历期和产卵前期, 以及较长的寿命 (Demard and Qureshi, 2023)。斯氏钝绥螨也能以芒果赤叶螨 *Oligonychus mangiferus* 和东方真叶螨 *Eutetranychus orientalis* 为猎物, 并表现出较高的内禀增长率和周限增长率 (Abou-Awad *et al.*, 2010; Yalçın *et al.*, 2023)。侧多食跗线螨 *Polyphagotarsonemus latus* 作为猎物时, 斯氏钝绥螨的内禀增长率和周限增长率分别达 0.13 和 1.13, 表明其可作为斯氏钝绥螨繁育的优良自然猎物 (Onzo *et al.*, 2012)。斯氏钝绥螨取食烟粉虱或温室白粉虱卵时, 其内禀增长率分别为 0.12 和 0.13, 表明这两种粉虱均可用于繁育斯氏钝绥螨 (Seiedy *et al.*, 2017; Hosseininia *et al.*, 2020)。韩玉华等 (2016) 发现, 斯氏钝绥螨以西花蓟马为猎物的总产卵量达 43.20 粒, 净增殖率为 33.15, 明确其以西花蓟马为猎物具有较好的发育和繁殖潜能。Nguyen 等 (2024) 的研究也表明, 斯氏钝绥螨以西花蓟马卵和第一若虫为食的内禀增长率均为 0.19。此外, 斯氏钝绥螨也能以橄榄片盾蚧 *Parlatoria oleae* 为食进行生长、发育和繁殖 (Helmy and Sholla, 2022)。

4.2 花粉繁育法

斯氏钝绥螨能利用多种植物花粉作为食物。研究发现, 斯氏钝绥螨取食阿月浑子 *Pistacia vera* (Kadkhodazadeh *et al.*, 2021)、海枣 *Phoenix dactylifera* (Barzkar *et al.*, 2023)、黄瓜 *Cucumis sativus*、丝瓜 *Luffa cylindrical* (罗春萍等, 2017)、蓖麻 *Ricinus communis* (Sweelam and Nasreldin, 2023)、玉米 (Onzo *et al.*, 2012)、石榴 *Punica granatum* (Kadkhodazadeh *et al.*, 2021) 和杏

Prunus armeniaca (Nemati *et al.*, 2019) 的花粉时, 其适合度与取食自然猎物相当甚至更高, 这些花粉可作为斯氏钝绥螨在自然猎物匮乏期的优质替代食物。

多代繁育试验进一步证明, 部分优质花粉可长期饲养斯氏钝绥螨, 并维持其对靶标猎物的控害效果。Ansari-Shiri 等 (2022) 发现, 斯氏钝绥螨以扁桃 *Prunus amygdalus* 花粉为食连续繁育 45 代后, 其净繁殖率、内禀增长率和周限增长率仍显著高于其以二斑叶螨为食的种群。Lamlom 等 (2024) 的研究指出, 斯氏钝绥螨以玉米花粉为食时, 第 11 代的内禀增长率和周限增长率分别高达 0.16 和 1.17。Pourbahram 等 (2022) 指出, 斯氏钝绥螨以番红花 *Crocus sativus* 花粉为食繁育 20 代后的内禀增长率 (0.18) 和周限增长率 (1.20) 与第 10 代相比无显著差异, 但其在第 20 代时对二斑叶螨的净捕食率 (C_0) 显著高于第 10 代, 表明番红花花粉能增强其捕食能力。类似地, Hadadi 等 (2022) 发现, 斯氏钝绥螨以宽叶香蒲 *Typha latifolia* 花粉为食 20 代后对二斑叶螨未成熟螨态的净捕食率仍高达 524 头。Yazdanpanah 等 (2023) 的研究也表明, 以吉氏苏木 *Caesalpinia gilliesii* 花粉为食的斯氏钝绥螨, 在第 10 代仍能捕食 677 头二斑叶螨若螨。

4.3 替代猎物繁育法

为提高斯氏钝绥螨的室内规模化繁育效率, 国内外学者评估了多种储藏物害螨作为其替代食物的适宜性, 以支持其长期发育与繁殖。其中, 甜果螨 *Carpoglyphus lactis* 是目前最常用的替代猎物 (郑苑等, 2019)。Hosseini 等 (2020) 研究发现, 斯氏钝绥螨取食甜果螨和二斑叶螨的净繁殖率、周限增长率和世代周期不存在显著差异。罗宾根螨 *Rhizoglyphus robini* 对斯氏钝绥螨也有较高的适合度。Sweelam 和 Nasreldin (2023) 发现, 斯氏钝绥螨取食罗宾根螨时的净繁殖率、内禀增长率和周限增长率与其取食二斑叶螨相当。除甜果螨和罗宾根螨外, 椭圆食粉螨 *Aleuroglyphus ovatus*、食根嗜木螨 *Caloglyphus rhizoglyphoides*、害嗜鳞螨 *Lepidoglyphus*

destructor 和腐食酪螨 *Tyrophagus putrescentiae* 等储藏物害螨同样可支持斯氏钝绥螨的规模化繁育 (Amira *et al.*, 2019; 郑苑等, 2019)。此外, 小腊螟 *Achroia grisella*、卤虫 *Artemia franciscana* 和地中海粉螟是捕食性昆虫的常用替代饲料, 其优异的饲养效果在斯氏钝绥螨中也得到证明 (Riahi *et al.*, 2017b; Momen *et al.*, 2019; Nemati *et al.*, 2019)。

4.4 人工饲料繁育法

人工饲料的研发显著提升了斯氏钝绥螨的规模化繁育效率。研究表明, 斯氏钝绥螨以基础饲料 AD0 (蜂蜜, 蔗糖, 色氨酸, 酵母提取物, 蛋黄) 添加柞蚕 *Antherea pernyi* 蛹血淋巴制成的人工饲料 AD2 后, 其内禀增长率 (0.18) 与取食甜果螨的种群 (0.18) 相当, 且其净繁殖率 (27.21) 显著高于取食甜果螨时 (20.58), 明确 AD2 可作为斯氏钝绥螨规模化繁育的人工饲料 (Nguyen *et al.*, 2013)。Nguyen 等 (2015) 在基础饲料 AD0 中添加黑水虻 *Hermetia illucens* 血淋巴, 发现斯氏钝绥螨的发育时间缩短, 产卵率和总产卵量增加, 内禀增长率升高。Riahi 等 (2017a) 也在其研究中发现, 斯氏钝绥螨取食由 80% 的基础饲料 AD0 和玉米花粉组成的 AD2, 及卤虫组成的 AD5 时, 有较高的内禀增长率和周限增长率, 明确玉米花粉和卤虫可作为较好的人工饲料来源。Eleawa 和 Waked (2015) 研发了由蜂蜜、葡萄糖、牛奶、酵母、新鲜蛋黄组成的基础饲料 AD0 和添加家蚕 *Bombyx mori* 血淋巴组成的人工饲料 AD1。研究发现, 斯氏钝绥螨取食 AD1 后的产卵量甚至高于其以二斑叶螨为食时的产卵量, 明确斯氏钝绥螨能以 AD1 为食进行规模化繁育。

5 斯氏钝绥螨对靶标猎物的生物防治效能研究

斯氏钝绥螨能捕食农林作物上包括害螨、粉虱和蓟马等多种小型节肢有害生物。国内外对斯氏钝绥螨的控害功能进行了广泛的研究及释放应用, 取得了较好的防治效果。

表 1 斯氏钝绥螨取食不同类型食物的种群参数

Table 1 Population parameters of <i>Amblyseius swirskii</i> feeding on different types of food					
食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C)/ Humidity (%)	种群参数 Population parameters	参考文献 References
自然猎物 Natural prey	瘿螨科 Eriophyidae	<i>Aceria mangiferae</i>	25/60	$R_0 = 23.82$; $r = 0.16$; $\lambda = 1.17$; $T = 20.10$	Abou-Awad <i>et al.</i> , 2010
		番茄刺皮瘿螨 <i>Aculops lycopersici</i>	25/70	$R_0 = 24.77$; $r = 0.20$; $\lambda = 1.22$; $T = 15.99$	Park <i>et al.</i> , 2011
		<i>Cisaberoptus kenya</i>	25/60	$R_0 = 22.26$; $r = 0.15$; $\lambda = 1.16$; $T = 21.20$	Abou-Awad <i>et al.</i> , 2010
		<i>Metaculus mangiferae</i>	25/60	$R_0 = 19.58$; $r = 0.14$; $\lambda = 1.16$; $T = 20.52$	Abou-Awad <i>et al.</i> , 2010
		侧多食跗线螨 <i>Polyphagotarsonemus latus</i>	25/80	$R_0 = 5.57$; $r = 0.13$; $\lambda = 1.13$; $T = 13.90$	Onzo <i>et al.</i> , 2012
	跗线螨科 Tarsonemidae	<i>Cenopalpus irani</i>	25/60	$R_0 = 11.68$; $r = 0.14$; $\lambda = 1.15$; $T = 17.56$	Bazgir <i>et al.</i> , 2018
	细须螨科 Tenuipalpidae	<i>Eotetranychus frosti</i>	25/60	$R_0 = 18.50$; $r = 0.18$; $\lambda = 1.19$; $T = 16.32$	Bazgir <i>et al.</i> , 2018
	叶螨科 Tetranychidae	东方真叶螨 <i>Eutetranychus orientalis</i>	25/70	$R_0 = 28.65$; $r = 0.22$; $\lambda = 1.24$; $T = 15.28$	Yalçın <i>et al.</i> , 2023
		芒果赤叶螨 <i>Oligonychus mangiferus</i>	25/60	$R_0 = 14.62$; $r = 0.13$; $\lambda = 0.14$; $T = 20.14$	Abou-Awad <i>et al.</i> , 2010
		柑橘全爪螨 <i>Panonychus citri</i>	25/60	$30.00 < R_0 < 40.00$; $0.15 < r < 0.18$; $1.15 < \lambda < 1.20$; $20.00 < T < 25.00$	Demard and Qureshi, 2023
		二斑叶螨 <i>Tetranychus urticae</i>	25/70	$R_0 = 13.35$; $r = 0.18$; $\lambda = 1.19$; $T = 14.35$	Hosseininia <i>et al.</i> , 2020

续表 1 (Table 1 continued)

食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C)/ Humidity (%)	种群参数 Population parameters	参考文献 References
自然猎物 Natural prey	粉虱科 Aleyrodidae	温室白粉虱 <i>Trialeurodes vaporariorum</i>	25/70	$R_0 = 7.30$; $r = 0.13$; $\lambda = 1.14$; $T = 15.74$	Hosseini <i>et al.</i> , 2020
		烟粉虱 <i>Bemisia tabaci</i>	25/70	$R_0 = 3.90$; $r = 0.12$; $\lambda = 1.13$; $T = 11.24$	Seiedy <i>et al.</i> , 2017
	蓟马科 Thripidae	西花蓟马 <i>Frankliniella occidentalis</i>	25/80	$R_0 = 33.15$; $r = 0.14$; $\lambda = 1.15$; $T = 24.97$	韩玉华等, 2016
	盾蚧科 Diaspididae	橄榄片盾蚧 <i>Prlatoria oleae</i>	25/70	$R_0 = 5.67$; $r = 0.06$; $\lambda = 1.06$; $T = 27.16$	Helmy and Sholla, 2022
	漆树科 Anacardiaceae	阿月浑子 <i>Pistacia vera</i>	25/60	$R_0 = 29.56$; $r = 0.19$; $\lambda = 1.21$; $T = 17.56$	Kadkhodazadeh <i>et al.</i> , 2021
	棕榈科 Arecaceae	海枣 <i>Phoenix dactylifera</i>	25/65	$R_0 = 20.44$; $r = 0.19$; $\lambda = 1.21$; $T = 15.76$	Barzkar <i>et al.</i> , 2023
	葫芦科 Cucurbitaceae	黄瓜 <i>Cucumis sativus</i>	25/75	$R_0 = 29.76$; $r = 0.13$; $\lambda = 1.14$; $T = 26.59$	罗春萍等, 2017
		丝瓜 <i>Luffa cylindrica</i>	25/75	$R_0 = 23.65$; $r = 0.12$; $\lambda = 1.13$; $T = 25.54$	罗春萍等, 2017
	大戟科 Euphorbiaceae	蓖麻 <i>Ricinus communis</i>	26/75	$R_0 = 12.09$; $r = 0.16$; $\lambda = 1.16$; $T = 15.96$	Sweelam and Nasreldin, 2023
	豆科 Fabaceae	吉氏苏木 <i>Caesalpinia gilliesii</i>	25/60	$R_0 = 30.82$; $r = 0.20$; $\lambda = 1.22$; $T = 17.52$	Yazdanpanah <i>et al.</i> , 2023
花粉 Pollen	禾本科 Gramineae	玉米 <i>Zea mays</i>	25/80	$R_0 = 18.67$; $r = 0.16$; $\lambda = 1.17$; $T = 18.92$	Onzo <i>et al.</i> , 2012
	鸢尾科 Iridaceae	番红花 <i>Crocus sativus</i>	25/60	$R_0 = 30.71$; $r = 0.16$; $\lambda = 1.17$; $T = 21.22$	Pourbahram <i>et al.</i> , 2022
	千屈菜科 Lythraceae	石榴 <i>Punica granatum</i>	25/60	$R_0 = 15.71$; $r = 0.19$; $\lambda = 1.20$; $T = 14.66$	Kadkhodazadeh <i>et al.</i> , 2021

续表 1 (Table 1 continued)

食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C)/ Humidity (%)	种群参数 Population parameters	参考文献 References
花粉 Pollen	蔷薇科 Rosaceae	扁桃 <i>Prunus amygdalus</i>	25/65	$R_0 = 17.88$; $r = 0.17$; $\lambda = 1.19$; $T = 16.54$	Ansari-Shiri <i>et al.</i> , 2022
		杏 <i>Prunus armeniaca</i>	25/65	$R_0 = 9.04$; $r = 0.11$; $\lambda = 1.11$; $T = 20.75$	Nemati <i>et al.</i> , 2019
	香蒲科 Typhaceae	宽叶香蒲 <i>Typha latifolia</i>	25/65	$R_0 = 11.87$; $r = 0.13$; $\lambda = 1.14$; $T = 18.24$	Hadadi <i>et al.</i> , 2022
替代猎物 Alternative prey	粉螨科 Acaridae	椭圆食粉螨 <i>Aleuroglyphus ovatus</i>	25/65	$R_0 = 11.51$; $r = 0.12$; $\lambda = 1.12$; $T = 21.03$	郑苑等, 2019
		食根嗜木螨 <i>Caloglyphus rhizoglyphoides</i>	30/65	$R_0 = 21.24$; $r = 0.14$; $\lambda = 1.15$; $T = 22.43$	Amira <i>et al.</i> , 2019
		罗宾根螨 <i>Rhizoglyphus robini</i>	26/75	$R_0 = 12.32$; $r = 0.18$; $\lambda = 1.19$; $T = 14.31$	Sweelam and Nasreldin, 2023
		腐食酪螨 <i>Tyrophagus putrescentiae</i>	25/65	$R_0 = 3.26$; $r = 0.05$; $\lambda = 1.06$; $T = 21.51$	郑苑等, 2019
	果螨科 Carpoglyphidae	甜果螨 <i>Carpoglyphus lactis</i>	25/65	$R_0 = 31.76$; $r = 0.19$; $\lambda = 1.21$; $T = 18.03$	郑苑等, 2019
	食甜螨科 Glycyphagidae	害嗜鳞螨 <i>Lepidoglyphus destructor</i>	30/65	$R_0 = 15.79$; $r = 0.12$; $\lambda = 1.13$; $T = 23.24$	Amira <i>et al.</i> , 2019
	卤虫科 Artemiidae	卤虫 <i>Artemia franciscana</i>	25/65	$R_0 = 17.90$; $r = 0.14$; $\lambda = 1.15$; $T = 21.29$	Riahi <i>et al.</i> , 2017b
	螟蛾科 Pyralidae	小腊螟 <i>Achroia grisella</i>	30/70	$R_0 = 15.20$; $r = 0.19$; $\lambda = 1.21$; $T = 14.99$	Momen <i>et al.</i> , 2019
		地中海粉螟 <i>Ephesia kuehniella</i>	25/65	$R_0 = 13.64$; $r = 0.12$; $\lambda = 1.13$; $T = 21.36$	Nemati <i>et al.</i> , 2019

续表 1 (Table 1 continued)

食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C) / Humidity (%)	种群参数 Population parameters	参考文献 References
人工饲料 Artificial diet	—	AD1: 5%蜂蜜, 5%蔗糖, 5%色氨酸, 5%酵母提取物, 10%蛋黄, 70%蒸馏水 (w/w) AD1: 5% honey, 5% sucrose, 5% tryptone, 5% yeast extract, 10% egg yolk, and 70% distilled water (w/w) AD2: 80%的 AD1 和 20% (w/w) 的柞蚕蛹的血淋巴 AD2: 80% AD1 supplemented with 20% (w/w) pupal hemolymph of <i>Antheraea pernyi</i>	25/70	$R_0 = 6.46$; $r = 0.10$; $T = 22.08$	Nguyen <i>et al.</i> , 2013
	—	AD1: 80%的 AD 和 20% (w/w) 的柞蚕蛹的血淋巴[AD: 5%蜂蜜, 5%蔗糖, 5%色氨酸, 5%酵母提取物, 10%蛋黄, 70%蒸馏水 (w/w)] AD1: 80% AD supplemented with 20% (w/w) pupal hemolymph of <i>A. pernyi</i> [AD: 5% honey, 5% sucrose, 5% tryptone, 5% yeast extract, 10% egg yolk, and 70% distilled water (w/w)] AD2: 40 g 的 AD 和 10 g 地中海粉螟卵研磨物 AD2: 40 g AD mixed with finely grinding 10 g of eggs of <i>E. kuehniella</i>	23/70	$R_0 = 27.21$; $r = 0.18$; $T = 18.30$ $R_0 = 24.71$; $r = 0.17$; $T = 18.49$	Nguyen <i>et al.</i> , 2014
	—	AD: 蜂蜜 (10 g), 葡萄糖 (10 g), 牛奶 (20 mL), 酵母 (5 g) 和新鲜蛋黄 (10 mL) AD: Honey (10 g), glucose (10 g), milk (20 mL), yeast (5 g) and fresh egg yolk (10 mL)	27/65	$R_0 = 23.23$; $r = 0.160$; $T = 19.65$ $R_0 = 22.76$; $r = 0.19$; $T = 16.84$	Eleawa and Waked, 2015
	—	AD1: 75%的 AD 和 25% (w/w) 的家蚕幼虫血淋巴 AD1: 75% AD supplemented with 25% (w/w) larval hemolymph of <i>Bombyx mori</i>	25/70	—	Nguyen <i>et al.</i> , 2015

续表 1 (Table 1 continued)

食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C)/ Humidity (%)	种群参数 Population parameters	参考文献 References
人工饲料 Artificial diet	—	AD5: 95%的 AD0 和 5% (w/w) 的黑水虻预蛹血淋巴 AD5: 95% AD0 supplemented with 5% (w/w) pre-pupal hemolymph of <i>Hermetia illucens</i> AD10: 90%的 AD0 和 10% (w/w) 的黑水虻预蛹血淋巴 AD10: 90% AD0 supplemented with 10% (w/w) pre-pupal hemolymph of <i>H. illucens</i> AD20: 80%的 AD0 和 20% (w/w) 的黑水虻预蛹血淋巴 AD20: 80% AD0 supplemented with 20% (w/w) pre-pupal hemolymph of <i>H. illucens</i> AD1: 5%蜂蜜, 5%蔗糖, 5%色氨酸, 5%酵母提取物, 10%蛋黄, 70%蒸馏水 (w/w) AD1: 5% honey, 5% sucrose, 5% tryptone, 5% yeast extract, 10% egg yolk and 70% distilled water (w/w) AD2: 80%的 AD1 和 20%的玉米花粉 AD2: 80% AD1 supplemented with 20% maize pollen AD3: 80%的 AD1 和 20%的 <i>Plusia gamma</i> 幼虫血淋巴 AD3: 80% AD1 supplemented with 20% larval hemolymph of <i>P. gamma</i> AD4: 80%的 AD1 和 20%的地中海粉螟卵 AD4: 80% AD1 supplemented with 20% <i>E. kuehniella</i> eggs AD5: 80%的 AD1 和 20%的去壳卤虫卵 AD5: 80% AD1 supplemented with 20% decapsulated cysts of <i>A. franciscana</i> AD6: 80%的 AD1 和 20%的地中海粉螟幼虫 AD6: 80% AD1 supplemented with 20% <i>E. kuehniella</i> larvae	25/70	$R_0 = 14.94$; $r = 0.18$; $T = 14.84$ $R_0 = 14.58$; $r = 0.19$; $T = 14.17$ $R_0 = 17.60$; $r = 0.21$; $T = 13.65$ $R_0 = 8.13$; $r = 0.09$; $\lambda = 1.09$; $T = 24.07$ $R_0 = 20.43$; $r = 0.15$; $\lambda = 1.16$; $T = 20.25$ $R_0 = 6.97$; $r = 0.10$; $\lambda = 1.10$; $T = 20.33$ $R_0 = 17.32$; $r = 0.14$; $\lambda = 1.15$; $T = 20.01$ $R_0 = 24.31$; $r = 0.16$; $\lambda = 1.17$; $T = 20.53$ $R_0 = 2.78$; $r = 0.05$; $\lambda = 1.05$; $T = 19.78$	Riahi <i>et al.</i> , 2017a

续表 1 (Table 1 continued)

食物类型 Food types	科名 Family	猎物种类/人工饲料配方 Prey species/Artificial diet	温度 (°C) / 相对湿度 (%) Temperature (°C)/ Humidity (%)	种群参数 Population parameters	参考文献 References
人工饲料 Artificial diet	—	AD7: 80%的 AD1 和 20% (w/w) 的复合微生物糖浆 (每 5 mL 含维生素 A 2 500 IU, D 400 IU, E 15 IU, B1 1 mg, B2 2.1 mg, B6 1 mg, B12 5.4 mcg, B5 5.13 mg, 水)	25/65	$R_0 = 7.75$; $r = 0.08$; $\lambda = 1.09$; $T = 24.86$	
		AD7: 80% AD1 supplemented with 20% multivitamin syrup (Each 5 mL of multivitamin syrup contains vitamin A 2 500 IU, vitamin D 400 IU, vitamin E 15 IU, vitamin B1 1 mg, vitamin B2 2.1 mg, vitamin B6 1 mg, vitamin B12 5.4mcg, vitamin B5 5.13 mg, and water in sufficient quantity)			
		AD8: 80%的 AD1 和 20%的牛血清蛋白			
		AD8: 80% AD1 supplemented with 20% bovine serum albumin			
		AD9: 80%的 AD1 和 20% (w/w) 的公牛精子			
		AD9: 80% AD1 supplemented with 20% bull sperm		$R_0 = 7.86$; $r = 0.09$; $\lambda = 1.10$; $T = 21.97$	

R_0 : 净繁殖率; r : 内禀增长率; λ : 周限增长率; T : 平均世代周期。内禀增长率 $r < 0$ 指斯氏钝绥螨种群处于负增长。
 R_0 : Net reproductive rate; r : Intrinsic rate of increase; λ : Finite rate of increase; T : Mean generation time. A finite rate of increase (r) < 0 indicates that the population of *A. swirskii* is experiencing negative growth.

5.1 捕食能力评价

捕食功能反应揭示了斯氏钝绥螨对多种害螨和害虫的控害潜能。研究显示, 斯氏钝绥螨能有效控制害螨番茄刺皮瘿螨 (Park *et al.*, 2010)、细须螨 *C. irani* (Bazgir *et al.*, 2020)、始叶螨 *E. frosti* (Bazgir *et al.*, 2020)、二斑叶螨 (Elmoghazy *et al.*, 2024)、朱砂叶螨 (王利平等, 2011)、土耳其斯坦叶螨 *Tetranychus turkestanii* (Rahmani Piyani *et al.*, 2021)、棉兰皱皮螨 *Suidasia medanensis* (Midthassel *et al.*, 2014) 和害虫西花蓟马 (Dalir *et al.*, 2021)、烟蓟马 *Thrips tabaci*、烟粉虱 (Nawar and Imam, 2019), 且其捕食功能反应均属于 Holling II 型。

斯氏钝绥螨对不同种猎物表现出选择偏好。在二斑叶螨和烟粉虱间, 斯氏钝绥螨更倾向于捕食二斑叶螨 (Soleymani *et al.*, 2016b)。相较于二斑叶螨若螨, 斯氏钝绥螨更偏好取食西花蓟马的第一若虫 (Xu and Enkegaard, 2010)。斯氏钝绥螨对西花蓟马第二若虫的捕食量显著高于豆大蓟马 *Megalurothrips usitatus* (禹云超等, 2019)。此外, 斯氏钝绥螨对同种猎物的不同虫态也具有显著选择性。相较于其他螨态, 斯氏钝绥螨能消耗更多的二斑叶螨卵 (Gyuris *et al.*, 2018)。斯氏钝绥螨对烟粉虱的取食偏好表现为卵 > 第一若虫 > 第二若虫 (Soleymani *et al.*, 2016a)。与茶黄蓟马 *Scirtothrips dorsalis* 成虫相比, 斯氏钝绥螨对若虫表现出明显的喜好 (Schoeller *et al.*, 2020)。

5.2 田间释放应用

目前, 国内关于斯氏钝绥螨田间应用的研究相对有限, 主要集中在对叶螨和蓟马的防控。研究表明, 在吐鲁番高温低湿环境下, 释放斯氏钝绥螨 14 d 后, 对黄瓜上叶螨的防效达到 99.93% (郭小虎等, 2021)。当黄瓜叶片上蓟马虫口数量为 5.50 头/叶时, 以 4.4 万头/667 m² 的比例释放该螨, 45 d 后蓟马的密度降低为 0 头/叶, 防效达到 100% (徐淑华等, 2021)。当烟草上蓟马

数量达 30 头/株时, 按益害比 10 : 1 释放斯氏钝绥螨, 40 d 后烟蓟马种群数量降低为 0 (杨海林等, 2015), 同时对蓟马传播的烟草番茄斑萎病 (TSWV) 的控制效果达 51% 以上 (穆青等, 2016)。

国外关于斯氏钝绥螨田间应用的研究较多, 其对粉虱的控制效果显著。在斯里兰卡辣椒田中, 释放斯氏钝绥螨 6 周后, 烟粉虱种群降至初始试验种群的 26.6%, 证明斯氏钝绥螨能够有效控制烟粉虱种群 (Perera and Senanayake, 2023)。Hoogerbrugge 等 (2011) 在温室试验中发现, 应用斯氏钝绥螨后, 草莓叶片上温室白粉虱的累计虫量显著低于对照组。斯氏钝绥螨也被用于防治害螨。例如, 当大豆上二斑叶螨种群密度为 1-3 头/叶时, 分别以 2、4、6 头/叶的密度释放斯氏钝绥螨, 其防效可达到 54.3%、69.7% 和 78.9% (Mesbah, 2016)。van Maanen 等 (2010) 报道, 在侧多食跗线螨初始数量为 40 头/株时, 以 1 : 20 的益害比释放斯氏钝绥螨 3 周后, 侧多食跗线螨的种群数量可控制在 4 头/株以下。Mohamed 等 (2022) 在石榴树上以 100 和 200 头/株密度释放斯氏钝绥螨, 20 周后对细须螨 *Tenuipalpus punicae* 和 *Tenuipalpus granati* 的平均防效分别为 75.81% 和 82.62%。斯氏钝绥螨还能将蓟马种群控制于经济阈值之下。Kutuk 等 (2011) 在大棚辣椒上以 50 头/m² 的密度释放斯氏钝绥螨, 在释放后的 13-23 周内, 西花蓟马的种群密度始终低于 2 头/花。Arthurs 等 (2009) 在温室中以 30 头/株的密度释放斯氏钝绥螨, 能将茶黄蓟马控制在 1 头/叶, 且在室外释放后可持续控制蓟马种群长达 63 d。此外, 斯氏钝绥螨也可用于柑橘木虱 *Diaphorina citri* 的防控, 应用 6 d 后, 暴露于斯氏钝绥螨的柑橘木虱卵死亡率是对照的 4 倍, 8 周后柑橘木虱成虫的种群数量降低至对照的 20% (Juan-Blasco *et al.*, 2012)。

5.3 协同增效技术

近年来, 为提升斯氏钝绥螨的生物防治效果, 研究者开发了多种增效技术 (图 1)。其中, 斯氏钝绥螨的预防性释放策略 (Predator-in-first,

PIF) 取得了显著成效, 即在靶标害虫种群建立前释放斯氏钝绥螨, 从而提高其对靶标猎物的防控效率 (del Mar Tellez *et al.*, 2017)。载体植物可蓄积预先释放的斯氏钝绥螨, 提升其在作物早期靶标猎物密度较低成功建立种群的可能性。Xiao 等 (2012) 发现, 斯氏钝绥螨释放到载体植物辣椒 MA、RM、EE 上 14 d 后, 相邻豆科作物上烟粉虱和蓟马的种群数量显著低于对照 (粉虱: 2.75 vs 379.50; 蓟马: 13.40 vs 235.40)。此外, 花粉的应用增加了预先释放的斯氏钝绥螨的繁殖能力。例如, 在甜椒开花前 2 周以 50、5 和 0.5 kg/hm² 的剂量撒施土耳其松 *Pinus brutia* 花粉, 在斯氏钝绥螨释放 5 周后, 其种群密度达到 3 头/叶, 并持续维持至第 10 周, 有效控制了西花蓟马种群 (Kutuk and Yigit, 2011)。同样地, 粉螨的应用也增加了斯氏钝绥螨的种群密度, 增强其对靶标猎物的防控效果。例如, 甜果螨和斯氏钝绥螨同时释放时, 西花蓟马的为害率为 12%, 低于仅释放斯氏钝绥螨时的 32% (Muñoz-

Cárdenas *et al.*, 2017)。

斯氏钝绥螨与多种天敌的联合应用显著提升了对靶标猎物的防控效果。斯氏钝绥螨和智利小植绥螨联合应用 8 周后, 番茄叶片上二斑叶螨的种群数量为 7.57 头/叶, 显著低于对照的 40.88 头/叶 (Yaşar *et al.*, 2024)。斯氏钝绥螨分别与捕食螨 *Cydnozeius negevi*、黄瓜新小绥螨或智利小植绥螨联合应用时, 均能有效控制辣椒 *Capsicum annuum* 上的烟粉虱和烟蓟马 (Barghout *et al.*, 2022)。联合释放斯氏钝绥螨和加州新小绥螨 (7 头成螨/叶), 同样能有效控制辣椒上的西花蓟马、烟粉虱和侧多食跗线螨 (Elhalawany *et al.*, 2024)。以 20 头/株或 10 头/株的密度联合释放斯氏钝绥螨与小花蝽 *Orius insidiosus*, 对茶黄蓟马的防控效率显著优于单独释放斯氏钝绥螨时的防效 (Doğramaci *et al.*, 2011)。斯氏钝绥螨分别和蒙氏桨角蚜小蜂 *Eretmocerus mundus* (Calvo *et al.*, 2009)、桨角蚜小蜂 *Eretmocerus eremicus* (Vafaie *et al.*, 2021)

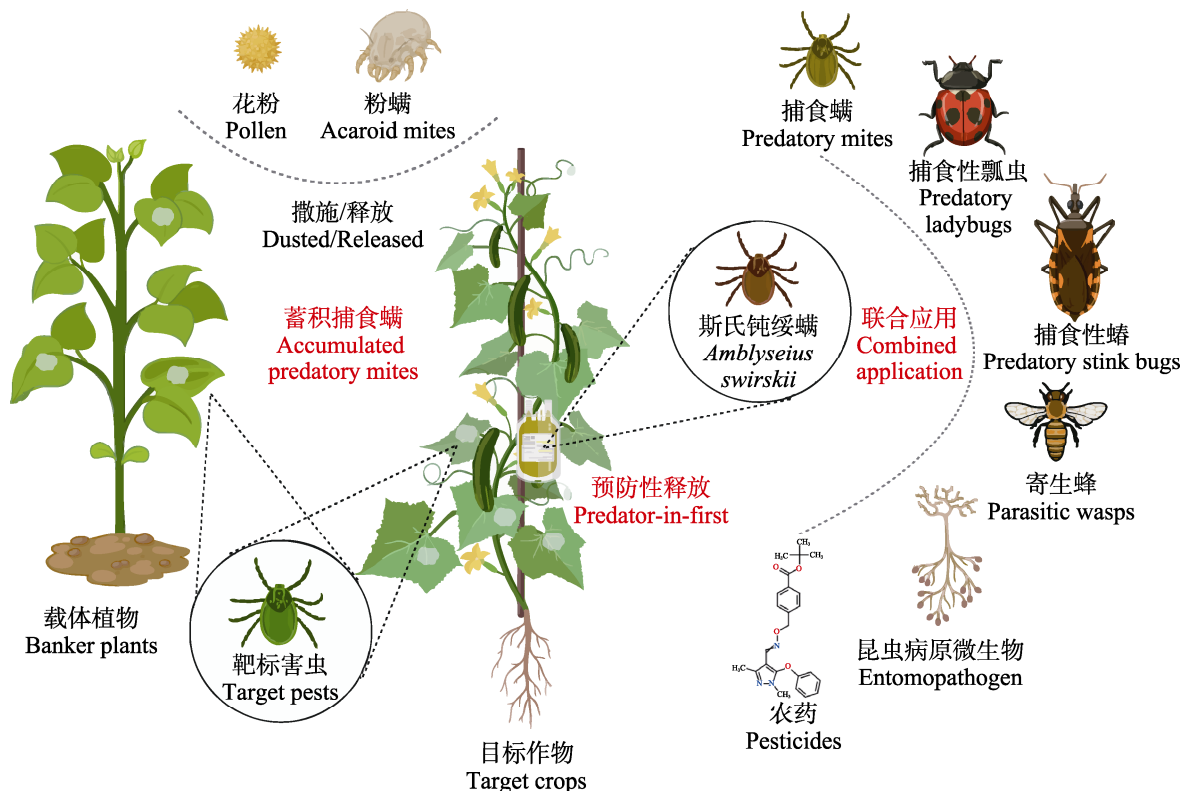


图 1 斯氏钝绥螨的协同增效模式

Fig. 1 The synergistic enhancement model of *Amblyseius swirskii*

联合应用,可提升对烟粉虱的控制潜能。斯氏钝绥螨与昆虫病原微生物的联合应用也表现出良好的协同效果。例如,当马铃薯上扶桑绵粉蚧 *Phenacoccus solenopsis* 的初始密度为 114-122 头/株时,斯氏钝绥螨和链格孢 *Alternaria destruens* 联合应用 5 周后,其卵和移动虫态的种群数量分别降至 9.22 粒/株和 7.11 头/株 (Aalaoui *et al.*, 2025)。斯氏钝绥螨和美丽链霉菌 *Streptomyces bellus* E23-2 菌株联合应用 5 周后, *Dactylopius opuntiae* 的种群数量显著降低 (El Aalaoui *et al.*, 2025)。斯氏钝绥螨还可传播球孢白僵菌 CQBB111 菌株的孢子,提升对九里香 *Murraya exotica* 上木虱的防控效能 (Zhang *et al.*, 2015)。此外,斯氏钝绥螨与选择性化学农药的协同应用也取得了显著进展。例如,双丙环虫酯 (Kumar *et al.*, 2018)、XXpire (Kumar *et al.*, 2017b) 和 氟吡呋喃酮 (Kumar *et al.*, 2017a) 对斯氏钝绥螨无毒害作用,联合施用显著提升了对烟粉虱的防效。

6 展望

国际上已系统验证斯氏钝绥螨在控制害螨、粉虱及蓟马类害虫方面的潜能,并实现其在设施农业中的规模化应用。然而,我国对斯氏钝绥螨的研究仍偏重于发育生物学和基础生态学特性,应用规模有限,制约其深入开发与推广。为进一步提升其在我国的本土化应用效能,需重点突破以下研究方向:

(1) 生态安全评估体系的系统构建: 斯氏钝绥螨作为一种引入天敌,在我国多地的淹没式释放 (如云南蓝莓园、花卉大棚) 可能引发生态风险,包括与本地天敌的生态位竞争、基因渗透及种群替代等生物入侵现象。因此,在其释放应用前需进行风险评估,系统开展其与本地天敌 (如巴氏新小绥螨、江原钝绥螨) 的共存或排除机制研究,明确资源利用重叠和种间互作模式;结合 MaxEnt 等生态位模型预测其在我国的潜在地理分布及适生区扩张趋势;建立基于种群动态与环境容量的释放阈值模型,制定分区域、分作物的差异化应用技术规程,实现“精准释放与生态

安全”的协同。

(2) 环境适应性机制的多维度解析: 现有研究多聚焦于单一环境因子 (温度、农药等) 对斯氏钝绥螨的胁迫效应,而在其抗逆品系选育和遗传稳定性以及多环境因子协同互作 (如高温耦合化学农药胁迫) 下的适应机制仍缺乏深入讨论。后续研究需整合多组学技术 (转录组、基因组) 挖掘关键抗逆基因及调控通路 (如热激蛋白家族、解毒酶系 P450s), 结合 RNAi、CRISPR/Cas9 等技术验证功能基因的抗性表型,从表观遗传调控 (DNA 甲基化、组蛋白修饰) 角度解析其跨代适应机制,为定向选育高适应性品系提供理论依据。

(3) 田间应用技术的集成与模式创新: 当前的应用研究多局限于实验室及小规模田间试验,亟需开展区域性联合释放示范,构建“作物-天敌-环境”互作的区域性释放动态模型;研发载体植物系统 (如茄子、辣椒),优化植物结构配置与花粉/猎物补给策略,提升早期定殖效率;发展多天敌协同技术 (如加州新小绥螨、东亚小花蝽等),明确种间互作规律与增效条件;建立与绿色防控产品 (如微生物农药) 的兼容使用技术标准,制定从释放时机、剂量到效果评估的全流程标准化规程。

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