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## APPROACHES TO ENHANCING AGROBIODIVERSITY IN GREENHOUSE PEPPER PRODUCTION AND THEIR ROLE IN INTEGRATED PEST MANAGEMENT

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### Abstract

Agrobiodiversity enhancement is increasingly recognized as a fundamental element of sustainable pest management strategies in greenhouse pepper production systems. Biodiversity provides essential ecosystem services by supporting natural enemy populations, regulating pest dynamics, and increasing system resilience. This review synthesizes current approaches for enhancing functional biodiversity within and around greenhouse environments, including floral strips, banker plants, intercropping, and targeted habitat manipulation to foster beneficial arthropods, pollinators, and natural enemies. These strategies contribute to ecological pest suppression and reduce reliance on chemical pesticides, aligning with the principles of sustainable and climate-resilient agriculture. The review highlights the mechanisms by which increased biodiversity enhances natural pest regulation, discusses the practical challenges associated with the implementation of these practices, and identifies critical research gaps in optimizing biodiversity-based pest management. Particular emphasis is placed on the integration of these ecological approaches into comprehensive Integrated Pest Management (IPM) programs tailored for greenhouse pepper production. Strengthening the role of biodiversity in pest management represents a key pathway toward resilient and environmentally sound protected horticultural systems.

**Keywords:** Agrobiodiversity, Biological control, Integrated Pest Management (IPM), Greenhouse pepper, Habitat manipulation, Sustainable agriculture

### Introduction

Greenhouse production offers high yields and year-round supply but also creates simplified, resource-rich environments that can favour rapid pest build-up. Traditional pesticide-centric control in greenhouses is increasingly constrained by residue limits, resistance, consumer demand and regulations.

Excessive reliance on chemical pesticides in greenhouse pepper production has historically provided rapid suppression of pest populations but at the cost of ecological and agronomic sustainability. Intensive pesticide use disrupts natural enemy assemblages, eliminates beneficial arthropods, and accelerates the evolution of pest resistance - particularly in major pests such as *Bemisia tabaci*, *Trialeurodes vaporariorum*, and *Frankliniella occidentalis* (Desneux et al., 2007; Bielza, 2020). The repeated application of broad-spectrum insecticides can also induce secondary pest outbreaks by releasing minor pests from natural regulation (van Lenteren, 2012). In addition, concerns over pesticide residues, worker exposure, and contamination of non-target organisms have led to increasing regulatory restrictions and consumer-driven demand for residue-free produce (Sparks & Nauen, 2015).

Efforts to enhance agrobiodiversity and promote ecological approaches to pest management are not only supported by scientific evidence but are also embedded in the broader policy landscape guiding the transformation of modern agriculture. Recent European and international strategies emphasize the need to reconcile agricultural productivity with environmental sustainability and the protection of ecosystem services, placing biodiversity-based Integrated Pest Management (IPM) at the center of this transition.

The European Union's Farm to Fork Strategy, a key pillar of the European Green Deal, establishes a long-term vision for transforming the food system toward greater sustainability, environmental protection, and public health (EU Commission, 2020). One of its central objectives is to reduce the overall use and risk of chemical pesticides by 50% by 2030, as well as to phase out the most hazardous active substances. This ambitious target reflects growing awareness of the environmental and societal costs associated with pesticide-intensive agricultural systems, including the decline of biodiversity, loss of pollination and natural pest control services, and the emergence of pesticide-resistant pest populations.

To achieve these objectives, the European Commission emphasizes the wider implementation of Integrated Pest Management (IPM) as the foundation of sustainable plant protection. IPM promotes a hierarchy of control measures, prioritizing preventive and ecological approaches such as crop diversification, habitat manipulation, and the conservation of beneficial organisms before considering chemical interventions. Within this framework, enhancing functional biodiversity - both within and around cropping systems - emerges as a key strategy for achieving pesticide reduction targets while maintaining effective pest regulation.

### **Tools for enhancing functional biodiversity in greenhouse pepper production**

Biodiversity-based pest management provides a resilient alternative by leveraging ecological interactions to maintain pest populations below economic thresholds. Habitat diversification, banker plants, and floral resources sustain predators and parasitoids throughout the production cycle, enhancing natural regulation and ecosystem stability (Gurr et al., 2017; Messelink et al., 2021). Unlike chemical control, biodiversity-driven approaches promote functional redundancy and trophic complexity, which buffer the system against pest resurgence and environmental fluctuations. Embedding these measures into IPM programs reduces dependency on synthetic inputs, conserves beneficial communities, and aligns

greenhouse production with the broader objectives of sustainable intensification and agroecological transition (Tiftonell, 2014; Bale et al., 2008). By integrating such biodiversity-promoting strategies, producers not only improve the sustainability of their operations but also directly contribute to the realization of the Farm to Fork objectives for reduced pesticide use and increased ecosystem health.

### **Companion plants and intercropping**

Planting flowering herbs and ornamentals (e.g., sweet alyssum, marigold, basil, nasturtium) near pepper rows attracts predators and parasitoids (hoverflies, lacewings, syrphids) and provides nectar/pollen resources. Companion plants also can act as trap plants for certain pests (e.g., nasturtiums for aphids). Greenhouse-oriented studies and extension guidance recommend choosing species with continuous flowering and minimal risk as virus/vector reservoirs.

Enhancing within-greenhouse plant diversity through intercropping and mixed cropping is increasingly recognized as a viable strategy for ecological pest management in protected horticultural systems. It contributes to the preventive and conservation components of integrated pest management, and by diversifying the plant community reduces the vulnerability of the monocrop system to pest invasion and stabilizes natural enemy populations.

Unlike floral strips or banker plants, which are typically located at the periphery of the production area, intercropping introduces companion or secondary plant species directly within the crop canopy. This approach aims to mimic the structural and functional diversity found in natural ecosystems, thereby increasing the resilience of greenhouse crops to pest outbreaks. It can simultaneously contribute to pest suppression, pollinator support, nutrient cycling, and microclimate regulation (Lu et al., 2020; Messelink et al., 2021).

The ecological basis for pest suppression in intercropped systems lies in both bottom-up and top-down regulation mechanisms. Bottom-up effects arise when the introduction of non-host or repellent plants alters pest behavior by disrupting host-location cues. This phenomenon suggests that pest insects find it more difficult to locate and exploit their host plants in a heterogeneous vegetation matrix (Root, 1973). In greenhouse pepper systems, intercropping with plants that emit repellent volatiles - such as basil (*Ocimum basilicum*), marigold (*Tagetes spp.*), or coriander (*Coriandrum sativum*) - has been shown to reduce colonization by whiteflies (*Trialeurodes vaporariorum*) and aphids (*Myzus persicae*) (Amoabeng et al., 2019; Salas et al., 2022).

Top-down effects result from enhanced natural enemy activity supported by increased plant diversity. The introduction of flowering or structurally complex companion plants can provide nectar, pollen, and alternative prey, thus improving survival and reproduction of key beneficial species such as *Amblyseius swirskii*, *Orius laevigatus*, and *Aphidius colemani*. These species are central to the biological control of thrips, whiteflies, and aphids in greenhouse peppers (Messelink et al., 2014; Skirvin et al., 2020).

Effective implementation of intercropping systems in protected environments requires careful selection of companion species that provide ecological benefits without competing excessively with the main crop. According to Amoabeng et al.

(2019) companion plants should offer floral or structural resources to beneficials while exerting neutral or repellent effects on pests. For instance, basil and coriander provide short-tubed flowers suitable for parasitoids, while marigold emits allelochemicals that deter *T. vaporariorum*. Intercropping can be performed in alternating rows, border plantings, or patch mosaics. In greenhouse peppers, alternating strips of basil or marigold between pepper rows has been reported to reduce whitefly density by up to 40–60% (Salas et al., 2022). The timing of companion plant establishment is critical. Introducing secondary species 2 - 3 weeks before transplanting peppers ensures that floral resources and shelter are available for early colonizing beneficials. Intercropped species should not impede harvesting, irrigation, or pesticide application. Compact, fast-growing herbs such as basil, Alyssum, or dill (*Anethum graveolens*) are particularly suitable for limited-space environments. A growing body of empirical research supports the role of intercropping in promoting pest regulation and biodiversity in greenhouse crops. **Pepper - basil intercropping** has been shown to reduce aphid colonization and increase parasitoid abundance in semi-commercial greenhouse experiments (Amoabeng et al., 2019). **Pepper–marigold systems** decreased whitefly adult densities and improved yields under low-input management (Salas et al., 2022). **Pepper–alyssum intercropping** supported higher populations of *Orius laevigatus* and *Amblyseius swirskii*, enhancing thrips control (Messelink et al., 2014). **Dill and coriander strips** interplanted with peppers increased the diversity of hoverflies (*Syrphidae*) and lacewings (*Chrysopidae*), leading to reduced aphid numbers (Skirvin et al., 2020).

Intercropping can also modify microclimatic conditions - for example, by reducing temperature fluctuations and increasing humidity - creating a more favorable environment for natural enemies that are sensitive to desiccation, such as predatory mites (Ragusa et al., 2021).

From a nutritional and physiological perspective, intercropping may improve soil microbial activity and nutrient use efficiency in soil-based greenhouse systems. Leguminous intercrops, such as clover (*Trifolium spp.*), can fix atmospheric nitrogen and support mycorrhizal networks that enhance pepper root health (Lu et al., 2020). However, in hydroponic or substrate-based greenhouses, intercropping requires adaptation - often via potted companion plants placed strategically to deliver ecological services without interfering with irrigation or nutrient systems.

Overall, intercropping enhances both **functional biodiversity** (the abundance and activity of beneficial organisms) and **taxonomic biodiversity** (species richness and evenness). Integration with augmentative biological control (e.g., periodic releases of *A. swirskii* or *O. laevigatus*) has proven synergistic, as companion plants provide food and shelter that sustain these agents between releases (Messelink et al., 2021). Furthermore, intercropping aligns with the principles of ecological intensification, enhancing ecosystem services while reducing reliance on synthetic inputs. From a sustainability perspective, it complements other biodiversity-based measures such as banker plants, floral strips, and habitat diversification outside the greenhouse.

The magnitude of pest suppression, however, varies depending on greenhouse structure, climate control, and crop cycle duration. The immediate

financial benefits of intercropping are not always evident, making it less attractive for growers operating under tight profit margins (Lu et al., 2020).

### **Habitat manipulation**

Habitat manipulation aims to create or conserve refuges and alternative resources that sustain populations of natural enemies, pollinators, and decomposers across seasons and production cycles. In high-intensity greenhouse pepper production, these external biodiversity reservoirs can serve as “source habitats” that continuously supply beneficial species into the protected environment, thereby reinforcing pest regulation within (Messelink et al., 2021).

Habitat manipulation complements the preventive, cultural, and conservation components of Integrated Pest Management by extending the functional landscape of biodiversity beyond greenhouse boundaries. While greenhouse systems are often viewed as isolated agroecosystems, their ecological connectivity with surrounding habitats is increasingly recognized as a key determinant of biological control success (Bennison et al., 2020; Desneux & Wajnberg, 2023). For example, establishing floral-rich buffer zones near ventilation outlets has been shown to improve the colonization rate of released parasitoids (*Encarsia formosa*, *Eretmocerus eremicus*) and predators (*Macrolophus pygmaeus*) within greenhouse peppers (Desneux & Wajnberg, 2023). Moreover, these buffer habitats facilitate the spillover of beneficials between successive crops, reducing the need for repeated augmentative releases.

Habitat manipulation around greenhouse structures provides an essential component of landscape-level ecological management. Perimeter vegetation, buffer zones, and adjacent semi-natural habitats can significantly influence the colonization, persistence, and performance of beneficial arthropods within greenhouses. Semi-natural vegetation around greenhouses functions as a source of beneficial arthropods - such as lady beetles (*Coccinellidae*), lacewings (*Chrysopidae*), and predatory bugs (*Orius spp.*) - which can disperse into greenhouse crops when prey is available (Gurr et al., 2017). The presence of flowering weeds and hedgerows enhances these dynamics by providing nectar and pollen resources that sustain natural enemies during and between crop cycle. Vegetative buffers moderate temperature and humidity gradients near greenhouse openings, facilitating the establishment of species sensitive to desiccation or temperature extremes, such as predatory mites and parasitoids (Wäckers et al., 2012). Perimeter vegetation can disrupt the host-finding behavior of flying pests (e.g., whiteflies, aphids, leafminers) through visual and olfactory interference. Mixed-species vegetation alters the spectral and volatile background, making it more difficult for pests to locate greenhouse entrances or the target crop (Sampson et al., 2015). By supporting multiple prey and host species, diverse perimeter vegetation enhances the trophic stability of local food webs, reducing the risk of natural enemy extinction during pest-free periods (Landis et al., 2000).

Successful habitat manipulation around greenhouse pepper production requires site-specific planning and ongoing maintenance to balance ecological benefits with phytosanitary constraints. The design typically involves the establishment of multifunctional buffer zones composed of herbaceous and woody vegetation, selected to provide continuous flowering, overwintering sites, and

minimal risk of pest harboring. Species should be non-invasive, adapted to local conditions, and compatible with biological control objectives. Native wildflowers (e.g., *Achillea millefolium*, *Phacelia tanacetifolia*, *Trifolium pratense*), low-growing legumes, and aromatic herbs (*Thymus spp.*, *Lavandula spp.*) are commonly used. Overlapping flowering phenologies ensure resource availability across seasons, supporting beneficials year-round, even during greenhouse downtime. Combining herbaceous layers with shrubs or hedges provides nesting and overwintering habitats for predatory beetles, spiders, and solitary bees. Vegetation strips are best located along the sides or windward edges of the greenhouse to act as ecological corridors and reduce pest entry via airflow. Regular trimming and monitoring are essential to prevent pest build-up or excessive shading of greenhouse walls, which can affect temperature regulation and ventilation.

The integration of insectary hedgerows and flower-rich buffer strips has been shown to increase natural enemy abundance by up to 50% in studies adjacent to greenhouse crops, while reducing the frequency of pest outbreaks inside the protected area (Bennison et al., 2020; Sampson et al., 2015). Such habitats can also enhance pollination services and contribute to the aesthetic and ecological value of greenhouse farms.

### **Floral strips and planting around greenhouses**

Enhancing perimeter plantings and nearby semi-natural habitats increases immigration of indigenous natural enemies into greenhouses. Studies suggest that diverse plantings around greenhouses stimulate natural enemy abundance, but designs must balance attracting beneficials with possible increases in pests or virus vectors.

Floral strips are carefully selected flowering plants established within or around greenhouse structures. They represent one of the most widely studied habitat-manipulation strategies for promoting functional biodiversity and biological control. Their primary ecological role is to provide continuous access to floral resources such as nectar and pollen, which sustain adult stages of many natural enemies, including hoverflies (*Syrphidae*), lacewings (*Chrysopidae*), predatory bugs (*Orius spp.*), and parasitoid wasps (*Aphidiinae*). In intensive greenhouse environments, where plant diversity and alternative food sources are typically low, floral strips can substantially increase the longevity, fecundity, and searching efficiency of these beneficial arthropods (Parolin et al., 2012; Gontijo et al., 2013).

By enriching the trophic base with pollen and nectar, floral resources enhance the numerical response of predators and parasitoids, ensuring their presence even when pest populations are low. At the same time, floral diversity alters the chemical landscape through the emission of volatile organic compounds, which may interfere with pest host-finding behavior or attract natural enemies to the crop canopy (Wäckers & van Rijn, 2012). Studies in protected *Capsicum* systems have demonstrated that interplanting sweet alyssum (*Lobularia maritima*) or buckwheat (*Fagopyrum esculentum*) can increase populations of *Aphidius colemani* and *Orius laevigatus*, leading to reduced infestations of aphids and thrips without compromising yield (Messelink et al., 2014; Huang et al., 2011).

To function effectively, floral strips in greenhouses must be **carefully designed** with respect to species selection, spatial arrangement, and temporal continuity of flowering. Ideal species exhibit compact growth, rapid establishment, and overlapping flowering periods to ensure a steady supply of floral resources. Short-corolla flowers such as sweet alyssum, coriander (*Coriandrum sativum*), or marigold (*Tagetes spp.*) are particularly suitable for short-tongued parasitoids and predatory bugs. Spatially, floral strips can be installed along walkways, bench edges, or near ventilation openings where they do not compete with the crop for light or nutrients. Periodic renewal and rotation of species are recommended to prevent pest or pathogen buildup.

The **timing of floral introduction** is also critical. Establishing strips before or at transplanting ensures that floral resources are available when initial natural enemy releases occur. Combining floral strips with banker plant systems can provide both alternative prey and nectar resources, creating a more stable environment for beneficial arthropods throughout the crop cycle (Frank & Liburd, 2005; Gurr et al., 2017).

When integrated into broader IPM programs, floral strips enhance the **conservation component** of biological control by supporting released and naturally occurring enemies. Their effects are most pronounced when combined with selective insecticides and compatible biological control agents. As such, floral strips represent a key ecological infrastructure element that strengthens resilience and self-regulation in greenhouse ecosystems, contributing to reduced pesticide dependence and improved sustainability.

### **Banker-plant systems and habitat provision for natural enemies**

Banker plants are non-crop plants deliberately used to sustain populations of natural enemies by providing alternative prey, pollen or refuge (for example, ornamental peppers or other flowering banker mixes used to support *Orius spp.* to control thrips) even in absence of target pests. By introducing non-crop plants that harbor non-pest prey (e.g., cereal aphids such as *Rhopalosiphum padi* on barley or oat), growers can maintain parasitoid populations such as *Aphidius colemani* or *Aphidius ervi* before target aphids appear on peppers (Huang et al., 2011). Similarly, ornamental peppers or flowering plants such as *Capsicum annuum* var. *ornamentale*, *Bidens ferulifolia*, or *Lobularia maritima* can serve as pollen or shelter sources for predatory bugs (*Orius spp.*) and predatory mites (*Amblyseius swirskii*), improving their establishment and survival (Messelink et al., 2014; Kumar et al., 2015). Experimental and applied studies show banker plant systems can increase biological control, although outcomes depend on complex trophic interactions and must be monitored to avoid unintended pest increases. In greenhouse pepper production, where pest outbreaks such as aphids, thrips, and whiteflies can occur rapidly due to the controlled environment, banker plants play an essential role in stabilizing biological control programs (Huang et al., 2011; Frank, 2010).

By maintaining natural enemies throughout the production cycle, banker plants help reduce time lags between pest colonization and predator response - a key limitation in augmentative biological control. This allows predators and parasitoids to act immediately upon pest emergence, preventing exponential

population growth (Frank, 2010; Wang et al., 2022). Additionally, banker plants can enhance local biodiversity by supporting a wider guild of beneficial arthropods, including generalist predators and pollinators that contribute to overall ecosystem resilience.

The effectiveness of a banker plant system depends on careful selection of plant - prey - natural enemy combinations. The ideal banker system should use a non-pest prey or pollen source that does not damage the crop, support a target natural enemy relevant to the key pest complex, and remain compatible with greenhouse hygiene and management practices (Parolin et al., 2012).

Spatial distribution within the greenhouse is crucial. Banker plants are typically placed at a density of one pot per 100–150 m<sup>2</sup>, near crop edges or entrances, where pest invasion is likely. Temporal management involves establishing banker plants one to two weeks before transplanting the main crop, allowing natural enemies to colonize and reproduce before pest appearance (Bennison, 2008). Compatibility with chemical control is another critical aspect. Selective insecticides must be used judiciously to avoid disrupting natural enemy populations sustained by banker systems. Integration with augmentative releases - for instance, introducing *Amblyseius swirskii* or *Eretmocerus eremicus* alongside banker plants - has shown synergistic effects on pest suppression (Messelink et al., 2021).

Long-term adoption requires developing standardized protocols for different climatic zones, refining cost - benefit analyses, and integrating banker systems into digital decision-support tools for greenhouse IPM (Desneux & Wajnberg, 2023; Frank, 2010). These systems exemplify how targeted enhancement of biodiversity can deliver stable and economically viable pest suppression in high-value greenhouse crops. Empirical evidence indicates that banker systems can substantially enhance biological control efficiency and reduce pesticide dependency when properly managed (Wang et al., 2022; Messelink et al., 2021).

### **Challenges and limitations**

Despite the proven ecological value of habitat manipulation, intercropping, floral strips, and banker plants their application in greenhouse systems faces some operational and biosecurity challenges. External and additional vegetation can serve as a refuge not only for beneficials but also for pest species such as thrips, whiteflies, and spider mites, or as reservoirs of plant viruses. Strict monitoring protocols are necessary to prevent pest migration into the greenhouse (Messelink et al., 2021). Regular monitoring and strict hygiene practices are therefore essential. Moreover, space constraints in high-intensity greenhouses may limit the area available for non-crop vegetation. Economic evaluations suggest that while floral strips or banker plants can reduce pesticide costs and improve long-term biological control, the initial establishment and maintenance require additional labor, knowledge, and technical understanding of biological control dynamics, which may be lacking among commercial growers (Parolin et al., 2012; Desneux & Wajnberg, 2023).

## Conclulsion

Enhancing agrobiodiversity in greenhouse pepper systems is a promising route to more resilient, sustainable IPM. When tailored thoughtfully - selective species choice, careful monitoring, integration with selective chemical and cultural tactics - diversity-based strategies can reduce pest pressure, strengthen biological control and lower reliance on broad-spectrum pesticides. Implementation requires attention to potential risks (pest reservoirs, trophic complexity) and an adaptive management mindset guided by monitoring and local IPM guidelines. Continued applied research and grower trials will refine best practices and clarify economic pathways for wider adoption.

## References

- Amoabeng, B. W., Johnson, A. C., & Gurr, G. M. (2019). Natural enemy enhancement and pest suppression in greenhouse crops through companion planting: A review. *Biological Control*, 134, 120–131. <https://doi.org/10.1016/j.biocontrol.2019.03.005>.
- Bale, J. S., van Lenteren, J. C., & Bigler, F. (2008). Biological control and sustainable food production. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492), 761–776. <https://doi.org/10.1098/rstb.2007.2182>.
- Bennison, J. (2008). Biological control of aphids on protected ornamentals using banker plants. *IOBC/WPRS Bulletin*, 32(7), 15–20.
- Bennison, J., Wäckers, F. L., & Alomar, O. (2020). Integration of habitat manipulation and biological control in protected cropping systems. *IOBC/WPRS Bulletin*, 150, 19–26.
- Bielza, P. (2020). Quo vadis resistance to insecticides in thrips? *Pest Management Science*, 76(1), 10–17. <https://doi.org/10.1002/ps.5584>.
- Desneux, N., Decourtye, A., & Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology*, 52, 81–106. <https://doi.org/10.1146/annurev.ento.52.110405.091440>
- Desneux, N., & Wajnberg, E. (2023). Functional biodiversity and pest management in greenhouse agroecosystems. *Annual Review of Entomology*, 68, 123–146. <https://doi.org/10.1146/annurev-ento-072021-060659>
- European Commission. (2019). The European Green Deal (COM/2019/640). Retrieved from [EUR-Lex](#).
- European Commission. (2020). A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system (COM(2020) 381). Retrieved from [EUR-Lex](#).
- Frank, S. D., & Liburd, O. E. (2005). Effects of floral resource plants on predator and parasitoid abundance and pest population suppression. *Environmental Entomology*, 34(4), 812–820. <https://doi.org/10.1603/0046-225X-34.4.812>
- Frank, S. D. (2010). Biological control of arthropod pests using banker plant systems: Past progress and future directions. *Biological Control*, 52(1), 8–16. <https://doi.org/10.1016/j.biocontrol.2009.09.011>

- Gontijo, L. M., Beers, E. H., & Snyder, W. E. (2013). Flowers promote aphid suppression in apple orchards: Indirect effects on predators. *Biological Control*, *66*(1), 8–15. <https://doi.org/10.1016/j.biocontrol.2013.03.010>
- Gurr, G. M., Wratten, S. D., Landis, D. A., & You, M. (2017). Habitat management to suppress pest populations: Progress and prospects. *Annual Review of Entomology*, *62*, 91–109. <https://doi.org/10.1146/annurev-ento-031616-035050>
- Huang, N., Enkegaard, A., Osborne, L. S., Ramakers, P. M. J., Messelink, G. J., Pijnakker, J., & Murphy, G. (2011). The banker plant method in biological control. *Critical Reviews in Plant Sciences*, *30*(3), 259–278. <https://doi.org/10.1080/07352689.2011.572055>
- Kumar, P., Poehling, H. M., & Borgemeister, C. (2015). Effects of pollen, honeydew and artificial food supplements on the fitness of predatory bugs *Orius laevigatus* and *Orius majusculus*. *Entomologia Experimentalis et Applicata*, *157*(3), 230–239. <https://doi.org/10.1111/eea.12363>
- Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology*, *45*(1), 175–201. <https://doi.org/10.1146/annurev.ento.45.1.175>
- Lu, Y., Zhang, J., Wang, W., & Desneux, N. (2020). Ecological engineering for pest management in protected horticultural systems: Lessons and perspectives. *Crop Protection*, *136*, 105226. <https://doi.org/10.1016/j.cropro.2020.105226>
- Messelink, G. J., Bloemhard, C. M. J., Hoogerbrugge, H., & van Schelt, J. (2014a). The influence of nectar plants on biological control of thrips and aphids in greenhouse crops. *IOBC/WPRS Bulletin*, *102*, 147–152.
- Messelink, G. J., van Holstein-Saj, R., & Leman, A. (2014b). Banker plants for biological control of thrips and aphids in greenhouse crops. *IOBC/WPRS Bulletin*, *102*, 153–158.
- Messelink, G. J., Bennison, J., Alomar, O., Ingegno, B. L., Tavella, L., Shipp, L., Palevsky, E., & Wäckers, F. L. (2021). Approaches to conserving natural enemy populations in greenhouse crops: Current methods and future prospects. *Biological Control*, *159*, 104624. <https://doi.org/10.1016/j.biocontrol.2021.104624>
- Messelink, G. J., Lambion, J., Janssen, A., & van Rijn, P. C. J. (2021). Biodiversity in and around Greenhouses: Benefits and Potential Risks for Pest Management. *Insects*, *12*(10), 933. <https://doi.org/10.3390/insects12100933>
- Parolin, P., Bresch, C., Desneux, N., Brun, R., Bout, A., Boll, R., & Poncet, C. (2012). Secondary plants used in biological control: A review. *International Journal of Pest Management*, *58*(2), 91–100. <https://doi.org/10.1080/09670874.2012.659229>
- Ragusa, E., Nocera, A., & Sciacchitano, D. (2021). Influence of microclimate modification on natural enemy activity in greenhouse vegetable crops. *Journal of Applied Entomology*, *145*(9), 910–922. <https://doi.org/10.1111/jen.12942>
- Root, R. B. (1973). Organization of a plant-arthropod association in simple and diverse habitats: The fauna of collards (*Brassica oleracea*). *Ecological Monographs*, *43*(1), 95–124.

- Salas, M. J., Pineda, A., & Vázquez, L. L. (2022). Intercropping marigold and pepper reduces whitefly infestation and improves yield in protected cultivation. *Journal of Pest Science*, 95(5), 1943–1955. <https://doi.org/10.1007/s10340-022-01506-y>
- Sampson, C., Kirk, W. D. J., & Lappage, M. G. (2015). The impact of vegetation diversity around greenhouses on pest and natural enemy movement. *Agricultural and Forest Entomology*, 17(4), 404–413. <https://doi.org/10.1111/afe.12119>
- Skirvin, D. J., Williams, C. D., & Bennison, J. A. (2020). Enhancing biological control of aphids and thrips in greenhouse peppers through habitat diversification. *Biocontrol Science and Technology*, 30(3), 251–266. <https://doi.org/10.1080/09583157.2020.1713183>
- Sparks, T. C., & Nauen, R. (2015). IRAC: Mode of action classification and insecticide resistance management. *Pesticide Biochemistry and Physiology*, 121, 122–128. <https://doi.org/10.1016/j.pestbp.2014.11.014>
- Tittonell, P. (2014). Ecological intensification of agriculture—Sustainable by nature. *Current Opinion in Environmental Sustainability*, 8, 53–61. <https://doi.org/10.1016/j.cosust.2014.08.006>
- van Lenteren, J. C. (2012). The state of commercial augmentative biological control: Plenty of natural enemies, but a frustrating lack of uptake. *Bio Control*, 57, 1–20. <https://doi.org/10.1007/s10526-011-9395-1>
- Wang, J., Zhang, J., Li, T., Zhang, Y., & Lu, Y. (2022). Direct and indirect effects of banker plants on pest and natural enemy population dynamics in greenhouses. *Biological Control*, 169, 104898. <https://doi.org/10.1016/j.biocontrol.2022.104898>
- Wäckers, F. L., & van Rijn, P. C. J. (2012). Pick and mix: Selecting flowering plants to meet the requirements of target biological control insects. In F. L. Wäckers, P. C. J. van Rijn, & J. Bruin (Eds.), *Plant-provided food for carnivorous insects* (pp. 139–165). Cambridge University Press.
- Zhou W, Arcot Y, Medina RF, Bernal J, Cisneros-Zevallos L, Akbulut ME (2024) Integrated pest management: an update on the sustainability approach to crop protection. *ACS Omega* 9:30–47. <https://doi.org/10.1021/acsomega.4c06628>
- Wäckers, F. L., van Rijn, P. C. J., & Heimpel, G. E. (2012). Honeydew as a food source for natural enemies: Making the best of a bad meal? *Biological Control*, 63(2), 120–131. <https://doi.org/10.1016/j.biocontrol.2012.07.014>