Research Review

© 2025, Centre for Advanced Research in Agricultural Sciences
Research Journal of Agricultural Sciences
Volume 16; Issue 04 (Jul–Aug 2025); pp 363–368

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Growing Together: Insect-Vegetable Relationships for Sustainable Agriculture

Nikhil Reddy K. S*[1, 5], Sugeetha G[2], Nagarjuna T. N[3], Ashish Kamal P[4] and Raghavendra A[5]

[1] Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga - 577 204, Karnataka, India
[2] Department of Entomology, College of Agriculture, V. C. Farm, Mandya - 571 405, Karnataka, India
[3] Department of Agricultural Entomology, Lokmangal College of Agriculture, Wadala - 413 222, Maharashtra, India
[4] Polytechnic of Agriculture (ANGRAU), Madakasira - 515 301, Andhra Pradesh, India
[5] Division of Genomic Resources, ICAR-NBAIR, Hebbal, Bengaluru - 560 024, Karnataka, India

Received: 28 Jun 2025; Revised accepted: 02 Aug 2025

Abstract

Insect-vegetable relationships provide mutual benefits through key ecological services such as pollination and biological pest control. Insects, particularly pollinators like honey bees and hoverflies, play a critical role in enhancing crop yields and quality by facilitating pollen transfer. Pollination has been shown to significantly increase yields in crops like tomatoes, squash, and bell peppers. Additionally, insects such as hoverflies and ground beetles contribute to biological pest control by suppressing harmful pest populations, reducing the need for chemical pesticides. The integration of habitat manipulation strategies, like intercropping and planting insectary plants, supports both pollination and pest control, fostering sustainable agricultural systems. Floral traits, including nectar composition and flower size, attract pollinators and sustain their populations, while mycorrhizal fungi improve soil health, influencing both plant growth and insect interactions. However, challenges such as climate change and landscape simplification can disrupt these mutual benefits, requiring adaptive agricultural practices. Practical applications, including neem-based pest control and intercropping systems, illustrate the potential for enhancing pollinator diversity and crop yields, thereby promoting the sustainability of insect-vegetable interactions in agriculture.

***Key words*:** Pollinators, Floral traits, Landscape, Intercropping, Ecological services

Insect-vegetable relationships play a vital role in maintaining ecological balance and enhancing agricultural productivity. These relationships provide mutual benefits, with insects offering essential services such as pollination and biological pest control [1], while vegetables contribute to the sustenance of these beneficial insect populations. Pollination, a critical service provided by various insect species, ensures the successful reproduction [2] of many vegetable crops, leading to increased seed yields [3] and improved fruit quality [4]. While some plants can self-pollinate or rely on wind or water, a significant number of vegetable crops require cross-pollination, where pollen from one plant is carried to another. Insects are the most effective vectors for this. As they forage for nectar and pollen, these insects inadvertently pick up pollen grains on their bodies and transfer them to other flowers, ensuring fertilization. Pollinators, such as honey bees, hoverflies, and squash bees, are crucial in transferring pollen between flowers, enabling the production of fruits and seeds, which are fundamental for vegetable crops [5-7]. In parallel, insects like hoverflies [8] and parasitic wasps [9] contribute to biological pest control, reducing the reliance on chemical pesticides and fostering healthier, more resilient ecosystems. Additionally, insects also contribute to natural pest control, reducing the need for harmful chemical pesticides [5] and supporting sustainable farming practices. This interplay between insects and vegetables not only improves crop productivity but also helps maintain biodiversity, enhance soil health, and promote overall ecosystem stability. This review explores the benefits of insect-vegetable interactions in modern agriculture, emphasizing the importance of pollination, pest control, and the mechanisms that sustain these mutual relationships. Understanding and fostering these insect-vegetable partnerships will be crucial in securing the future of global food production while promoting ecological health and resilience.

Mutual benefits of insect- vegetable relationships

Pollination services

Insects are primary pollinators of many vegetables, facilitating the transfer of pollen between flowers, which is essential for fruit and seed production. For example, in pumpkin cultivation, honey bees (*Apis dorsata*) are the dominant pollinators, contributing significantly to crop yield and quality [6]. Similarly, hoverflies (*Eupeodes corollae*) provide pollination services in greenhouse-grown crops like tomatoes, melons, and strawberries, enhancing fruit set and weight [8]. The importance of pollination extends beyond individual crops to entire cropping systems. Intercropping industrial hemp and cowpea with squash, a pollinator-dependent crop, has been

***Correspondence to:** Nikhil Reddy K. S, E-mail: nikhilreddy1718@gmail.com; Tel: +91 9902583799

Citation: Nikhil Reddy KS, Sugeetha G, Nagarjuna TN, Ashish Kamal P, Raghavendra A. 2025. Growing together: Insect-vegetable relationships for sustainable agriculture. *Res. Jr. Agril. Sci*. 16(4): 363-368.

shown to increase pollinator abundance and diversity, leading to higher squash yields [7]. Pollination enhances vegetable yields significantly, as seen in tomatoes and chilies [10], while improving fruit quality in bell peppers through intercropping with flowering plants. Vegetables also support pollinators by providing crucial nectar, pollen, and foraging habitats [11], thereby contributing to the ecology of agricultural landscapes. Effect of pollination in different crops represented in (Table 1).

Table 1 Key pollinators and their impact on vegetable crops

Crop	Key Pollinators	Yield impact	References
Squash	Squash bees (*Peponapis limitaris*)	Increased yield by 155-161% compared to monocrop	[7], [12]
Cucumber	Honey bees, native bees	Pollination accounted for 75% of yield increase	[13]
Tomato	Stingless bees (*Tetragonula laeviceps*)	Increased fruit set by 2-3 times compared to self-pollination	[10]
Bell pepper	*Paratrigona lineata, Apis mellifera*	Heavier and larger fruits due to pollination	[14]
Onion	*Apis cerana indica*	Higher seed yield through open pollination	[15]
Pumpkin	Diverse pollinator species	Functional diversity improved seed set	[16]

Biological pest control

In addition to pollination, insects play a critical role in biological pest control. Hoverflies, for instance, not only pollinate crops but also suppress aphid populations, reducing the need for chemical pesticides [5]. Similarly, ground beetles and parasitic wasps contribute to pest control in vegetable crops, protecting crops from damage caused by herbivorous insects [17]. The integration of pest control and pollination services is a key aspect of sustainable agriculture (Table 2). Studies have shown that these services can interact in complex ways, with pollination enhancing the effectiveness of pest control and vice versa [18]. For example, in cotton production, pollination has been shown to mitigate the negative effects of pests on crop yield, particularly under high pest pressure [18]. Habitat manipulation, such as the use of insectary plants, can attract and support populations of beneficial insects. For example, planting *Phacelia tanacetifolia* in the margins of cereal fields has been shown to enhance the biological control of aphids by hoverfly larvae. This approach provides a source of pollen and nectar for adult hoverflies, which in turn increases their oviposition rates and the subsequent predation of aphids by their larvae [19-20]. Similarly, the use of trap crops in combination with insectary plants can concentrate pest populations and suppress them through enhanced natural enemy activity, as demonstrated in organic cabbage agro-ecosystems [21]. Certain plants can serve dual roles as both habitat manipulation tools and sources of botanical insecticides. They often contain compounds that are toxic or repellent to pests. Unlike many synthetic pesticides, botanical insecticides tend to be more biodegradable and have a lower impact on the environment. Importantly, many are less harmful to beneficial insects than their synthetic counterparts. For example, plants from the families Apiaceae, Asteraceae, and Lamiaceae have been used for both habitat manipulation and insecticidal purposes. This dual functionality can enhance pest control while providing resources for natural enemies [22].

Table 2 Comparison of crops, pollinators, and pest control methods

Crop	Pollinators	Pest control methods	References
Pumpkin	Honey bees (*Apis dorsata*)	Neem-based botanicals	[6]
Squash	Sweat bees, bumble bees	Intercropping	[7]
Tomatoes	Hoverflies (*Eupeodes corollae*)	Augmentative biological control	[8]
Okra	Bees, flies, wasps	Soil fertilization	[23]
Cabbage	Bees, parasitic wasps	Companion planting (basil)	[9]

Mechanisms sustaining mutual benefits

Floral traits and floral rewards

Floral traits such as nectar composition, flower size, shape, color, and scent play a critical role in attracting pollinators and facilitating mutualistic interactions. These traits are often finely tuned to meet the needs of specific pollinators, ensuring efficient pollination and energy transfer. Nectar is one of the most important floral rewards, primarily composed of sugars, amino acids, and secondary metabolites. The quantity, concentration, and chemical composition of nectar influence pollinator attraction and foraging behavior. For instance, flowers visited by birds often produce dilute nectar with high volumes, while insect-pollinated flowers tend to produce more concentrated nectar [24]. The chemical composition of nectar, including secondary metabolites like alkaloids and phenolics, can also protect nectar from theft by non-pollinating insects and enhance pollinator memory and foraging efficiency [25]. The size and shape of flowers are critical for facilitating pollinator access to nectar and pollen. For example, long, tube-shaped flowers are often associated with pollinators like hummingbirds and certain bees, which have long proboscises [24]. Similarly, the symmetry and orientation of flowers can influence the efficiency of pollen transfer during pollinator visits [26]. Floral color and scent are key signals that guide pollinators to flowers. Volatile organic compounds (VOCs) emitted by flowers are complex signals that convey information about nectar quality and quantity. These signals are often used by pollinators to evaluate the rewards offered by a flower before landing [27]. Floral color, on the other hand, is often tuned to the visual preferences of specific pollinators. For example, flowers pollinated by bees tend to have UV-reflecting colors, while bird-pollinated flowers often exhibit red or orange hues [24].

Floral rewards, including nectar and pollen, are essential for sustaining the mutualistic relationship between plants and pollinators. These rewards not only provide pollinators with energy and nutrients but also influence their behavior and health. Nectar is the primary energy source for many pollinators, such as bees and butterflies. The sugar concentration and volume of nectar are critical for meeting the energy demands of pollinators. For example, flowers with high nectar rewards often attract pollinators that require large amounts of energy, such as hummingbirds [24]. Pollen is a rich source of proteins and lipids, which are essential for pollinator health and reproduction. Bees, in particular, rely on pollen to feed their larvae and sustain colony growth [28]. The chemical composition of pollen can also influence pollinator health by providing antioxidants and other beneficial compounds [25].

Floral rewards can also influence pollinator behavior and health. For example, certain secondary metabolites in nectar, such as alkaloids, can enhance pollinator memory and foraging efficiency [25]. Additionally, the antioxidant properties of floral rewards can protect pollinators from oxidative stress, thereby improving their overall health [25].

Soil health and mycorrhizal fungi

Soil health plays a crucial role in mediating plant-insect interactions. Mycorrhizal fungi improve plant nutrient uptake, particularly phosphorus and nitrogen, which are critical for plant growth and defense. For instance, studies have shown that arbuscular mycorrhizal fungi (AMF) increase plant biomass and reproductive potential [29-30]. This enhanced growth can lead to changes in leaf and root chemistry, making plants more or less susceptible to herbivores. Mycorrhizal fungi, which form symbiotic relationships with plant roots, can alter plant traits such as tissue nutrients, defensive chemicals, and floral traits, influencing both herbivory and pollination [30]. For example, mycorrhizal fungi from organic farms have been shown to increase root cucurbitacin C, a defensive chemical in cucumber, which may influence herbivore preference and population dynamics [30]. Similarly, other studies have found that mycorrhizal colonization can lead to the production of phenolics and other secondary metabolites, which play a role in plant defense [31]. The performance of herbivores on mycorrhizal plants can vary depending on the fungal species and the type of herbivore. For example, chewing insects tend to perform better on mycorrhizal plants, while sucking insects, such as aphids, may be negatively affected [32]. These differences highlight the complexity of mycorrhizal-plant-herbivore interactions.

Landscape management and habitat diversity

Agricultural landscapes with high structural and compositional heterogeneity provide a variety of resources and habitats for pollinators and natural enemies. For instance, landscapes with diverse land-use types, such as a mix of croplands, grasslands, and seminatural habitats, support greater biodiversity and ecosystem service delivery [33]. The presence of seminatural habitats, such as hedgerows, woodlots, and flower-rich areas, is particularly important for sustaining pollinators and natural enemies [34-35]. Seminatural habitats, such as woody habitats and flower-rich areas, provide refuge and foraging resources for beneficial insects, supporting both pollination and pest control [36]. For example, in pumpkin fields, the abundance of natural enemies and pollinators has been shown to be positively related to the supply of flowers in adjacent habitats [36]. In California almond orchards, wild pollinators play a crucial role in pollination, even in the presence of managed honey bees. The abundance of wild pollinators, such as hoverflies and wild bees, is higher in orchards with adjacent seminatural habitats or vegetation strips [37]. Organic farming practices and the restoration of high-quality habitat strips along field edges further enhance pollinator diversity and abundance, ensuring robust pollination services [37-38].

Factors influencing mutual benefits

1. *Agricultural practices*

Agricultural practices, such as crop rotation, intercropping, and soil management, can enhance or disrupt the mutual benefits of insect-vegetable relationships. For example, intercropping cabbage and basil has been shown to reduce aphid densities and increase parasitism, highlighting the potential of companion planting for biological pest control [9]. Similarly, the use of organic farming practices has been associated with higher pollinator diversity and abundance in some cropping systems [36]. However, the benefits of organic farming can vary based on landscape context and specific crop types, indicating a need for tailored approaches [39]. Techniques like no-till farming and mulching enhance the survival of beneficial insects, further supporting pest management [40].

2. *Biodiversity and species richness*

Pollinator and natural enemy richness directly support ecosystem services, such as pollination and pest control, independent of their abundance, with up to 50% of the negative effects of landscape simplification on these services arising from losses in species richness, adversely affecting crop yields [41]. Diversified farming systems can increase species richness by 26% on average, enhancing the abundance of beneficial species while reducing pest populations, particularly when located near natural habitats, which bolster natural enemies, while those situated farther away enhance pollinator abundance [42]. Additionally, landscape heterogeneity, characterized by high edge density, improves pollination and pest control services, resulting in higher crop yields [43]. The availability and diversity of floral resources are crucial for supporting wild bee populations and enhancing pollination [44], as flower-rich habitats and intentional plant selection can significantly boost the diversity of pollinators and natural enemies, promoting vital ecosystem services [45]. However, despite the well-documented importance of biodiversity in supporting these services, challenges in implementing biodiversity-friendly practices on a large scale persist, influenced by factors such as economic profitability, landscape context, and specific farm needs. Additionally, the variability in pollinator responses to organic farming and other conservation strategies suggests that tailored approaches may be necessary to achieve optimal outcomes [39].

3. *Climate change and environmental factors*

Climate change can cause phenological mismatches between plants and their pollinators, leading to reduced pollination success. For example, warming can advance plant flowering times without a corresponding shift in pollinator emergence, resulting in fewer interactions and reduced seed production [46-47]. Insect phenology is also affected, with some species experiencing advanced spring emergence and delayed winter diapause, which can alter their abundance and interactions with plants [48]. Rising temperatures and altered precipitation patterns can reduce the abundance and effectiveness of pollinators. For instance, bumblebee populations are sensitive to changes in temperature and precipitation seasonality, which can lead to declines in their populations and reduced pollination services. Changes in environmental conditions, such as increased temperatures and drought, can affect the quality and quantity of floral resources, further impacting pollinator health and behavior [49-50]. Climate change can increase pest pressure by expanding the geographic range of pests, increasing their survival rates, and altering their synchrony with host plants. This can lead to increased crop damage and challenges in pest management [51-52]. The effectiveness of biological control methods may be reduced due to mismatches between pests and their natural enemies, necessitating adaptive management strategies [53]. While climate change poses significant challenges to pollination and pest control services, it also presents opportunities for adaptation. Strategies such as climate-smart integrated pest and pollinator management (CSIPPM) can help mitigate these impacts by incorporating climate resilience into agricultural practices [54].

Effect of insecticides on insect pests within the vegetable ecosystem

Insecticides play a crucial role in managing insect pests in vegetable ecosystems, but their use must be carefully considered due to potential environmental and ecological impacts. This response explores the effects of various insecticides on insect pests, their efficacy, and their broader implications for the vegetable ecosystem. Chlorantraniliprole and spiromesifen have been shown to be highly effective against fruit borers (*Helicoverpa armigera*) and two-spotted spider mites (*Tetranychus urticae*) in tomato crops. Chlorantraniliprole, when applied at 0.15 ml/liter, significantly reduced fruit borer larvae and damage, while spiromesifen at 0.5 ml/liter effectively controlled spider mite populations. The combination of these two insecticides provided the most effective control [55]. Chlorantraniliprole has shown superior efficacy against *H. armigera*, with significant reductions in larval populations and increased yield in tomato crops [56]. It also demonstrated the highest cost-benefit ratio and yield increase when used against shoot and fruit borers in brinjal, outperforming other application methods like soil drenching [57]. Emamectin benzoate has also been effective against *H. armigera*, significantly reducing larval counts and increasing fruit yield [58]. Chlorantraniliprole and flubendiamide, have been evaluated for their efficacy against shoot and fruit borers (*Leucinodes orbonalis*) in brinjal. Foliar applications of these insecticides were found to be more effective than soil drenching or seedling dipping, with chlorantraniliprole showing the highest cost-benefit ratio and yield increase [59]. Spinosad, methoxyfenozide, and diflubenzuron have been tested against *Spodoptera littoralis* in tomatoes. Spinosad demonstrated the highest toxicity, with 91.38% mortality in the initial effect and 100% mortality in the residual effect. The pre-harvest intervals for these insecticides were 3, 7, and 10 days, respectively, ensuring safety for consumption [60].

Practical applications

Pumpkin cultivation: In pumpkin cultivation, the use of neem-based botanicals has been shown to effectively manage the red pumpkin beetle (*Raphidopalpa foveicollis*) while conserving pollinators [6]. The active ingredient azadirachtin impacts insect metabolic processes, including protein synthesis and chitin formation, which are critical for pest survival [61]. Neem-based pest control aligns with sustainable pest management (SPM) principles, which aim to reduce ecological disturbances and promote biodiversity. The preservation of pollinator diversity, particularly honey bees, is essential for maintaining the mutual benefits of insect-vegetable relationships in pumpkin cultivation [6]. While neem-based botanicals are effective in managing pests and conserving pollinators, their economic viability compared to synthetic pesticides can be a concern. Studies indicate that neem products may offer lower profit margins due to their relatively lower efficacy in some cases, such as in bottle gourd cultivation [62]. This highlights the need for further research and development to enhance the cost-effectiveness of neem-based solutions in diverse agricultural contexts.

Intercropping systems: Intercropping industrial hemp and cowpea with squash significantly increases pollinator abundance compared to monocropping systems. The study found that intercropped systems recorded a 79.1% increase in pollinator abundance, whereas monocropped systems only showed a 21.9% abundance [7]. This substantial increase highlights the potential of polyculture systems to attract a higher number of pollinators, which is crucial for pollinator-dependent crops like squash. In addition to abundance, intercropping also enhances pollinator diversity. Sweat bees and bumble bees were identified as the most abundant pollinators in the intercropped systems. The Squash + Cowpea intercropping system exhibited the highest diversity of pollinators, indicating that the combination of these crops creates a more attractive habitat for various pollinator species [7]. This diversity is essential for maintaining ecosystem services and ensuring robust pollination for all crops involved. The increased pollinator abundance and diversity in intercropped systems directly translate to higher crop yields. Squash, a pollinator-dependent crop, showed a significant increase in yield when intercropped with hemp or cowpea. Specifically, the Hemp + Squash system resulted in a 155% increase in squash yield, while the Squash + Cowpea system achieved a 161% increase compared to squash monocrop [7]. Similarly, hemp yields improved by 64% in the Hemp + Cowpea system and by 165% in the Hemp + Squash system, demonstrating the mutual benefits of intercropping for both squash and hemp [7].

Greenhouse horticulture: The presence of diverse pollinators, including hoverflies, supports functional complementarity, enhancing pollination success and crop output [63]. Hoverfly larvae are effective predators of aphids, significantly reducing aphid populations in crops like strawberries, melons, and tomatoes. In controlled experiments, hoverflies reduced aphid numbers by up to 99% in melons and 70% in strawberries [8]. Augmentative releases of *E. corollae* in greenhouses have been shown to increase fruit set and weight while controlling aphid populations effectively. For example, specific release rates led to 95% fruit set in tomatoes and significant aphid suppression in melons and strawberries [8]. The development of efficient breeding methods for *E. corollae* facilitates their large-scale application in greenhouse horticulture, promoting their role in sustainable agriculture [5].

CONCLUSION

The mutual benefits between insects and vegetables are foundational to sustainable agricultural practices, offering enhanced productivity, improved crop quality, and ecological resilience. Insects, through their roles as pollinators and natural pest controllers, provide indispensable services that support vegetable growth and health. Practices like intercropping, habitat conservation, and organic farming support these interactions, fostering biodiversity. However, climate change and agricultural intensification threaten these partnerships. By adopting innovative strategies and adaptive management, farmers can protect and enhance insect-vegetable relationships. Emphasizing these connections is vital for securing food production and environmental health, ensuring resilient and productive agricultural systems for the future.

LITERATURE CITED

1. Saleem M, Fatima A, Rehman A, Aroob T, Aleem A, Shahbaz M, Naveed H, Majeed A, Nawaz M, Gulsher M. 2024. Insect symphony: Understanding the role of entomology in ecosystem harmony. *Jr. Phys. Biomed. Biol. Science* 2024(1): 26-26.

2. Negi N, Sharma A, Chadha S, Sharma PC, Sharma P, Thakur M, Yankit P, Kaur M. 2020. Role of pollinators in vegetable seed production. *Jr. Entomol. Zool. Studies* 8(5): 417-422.
3. Tanda AS. 2019. Entomophilous crops get better fruit quality and yield: An appraisal. *Indian Jr. Entomol*. 81(2): 227-234.
4. Bartomeus I, Potts SG, Steffan-Dewenter I, Vaissiere BE, Woyciechowski M, Krewenka KM, Tscheulin T, Roberts SP, Szentgyörgyi H, Westphal C, Bommarco R. 2014. Contribution of insect pollinators to crop yield and quality varies with agricultural intensification. *PeerJ* 2: e328.
5. Li H, Wu K. 2023. An efficient breeding method for *Eupeodes corollae* (Diptera: Syrphidae), a pollinator and insect natural enemy in facility-horticulture crops. *Horticulturae* 9(6): 664.
6. Umesh SR, Naik ST, Karthik V, Kumar KBC, Hadimani BN, Vyas A, Gangaraj R. 2024. Efficacy of botanicals against red pumpkin beetle and their impact on pollinator diversity in pumpkin (*Cucurbita pepo* L.) cultivation. *Indian Jr. Horticulture* 81(3): 266-270.
7. Dingha BN, Mukoko GN, Egbon IN, Jackai LE. 2024. Intercropping industrial hemp and cowpea enhances the yield of squash—a pollinator-dependent crop. *Agriculture* 14(4): 636.
8. Li H, Wyckhuys KAG, Wu K. 2023b. Hoverflies provide pollination and biological pest control in greenhouse-grown horticultural crops. *Front. Plant Science* 14: 1118388.
9. Jahnke SM, Redaelli LR, Pretz VF. 2023. Effect of cabbage and basil intercropping on conservative biological control of aphids. *Desar. Local Sostenible* 16(47): 2648-2668.
10. Mubin N, Kusmita AO, Rohmah A, Nurmansyah A. 2022. Estimated economic value of pollination by *Tetragonula laeviceps* (Hymenoptera: Apidae: Meliponini) on tomato and chili. *Jr. Biol. Divers* 23(5): 2544-2552.
11. Kumar K, Fartyal RS, Kanwal KS, Khanduri SK, Topal P. 2024. Diversity and flower-visiting frequency of insect pollinators associated with mustard blooms (*B. campestris*) in Kullu Valley, Himachal Pradesh. *Environ. Conserv. Jr.* 25(4): 1120-1126.
12. Canto-Aguilar MA, Parra-Tabla V. 2000. Importance of conserving alternative pollinators: Assessing the pollination efficiency of the squash bee, *Peponapis limitaris*, in *Cucurbita moschata* (Cucurbitaceae). *Jr. Insect Conservation* 4(3): 201-208.
13. Motzke I, Tscharntke T, Wanger TC, Klein A-M, Motzke I. 2015. Pollination mitigates cucumber yield gaps more than pesticide and fertilizer use in tropical smallholder gardens. *Jr. Appl. Ecology* 52(1): 261-269.
14. Pereira ALC, Taques TC, Valim JOS, Madureira AP, Campos WG. 2015. The management of bee communities by intercropping with flowering basil (*Ocimum basilicum*) enhances pollination and yield of bell pepper (*Capsicum annuum*). *Jr. Insect Conservation* 19(3): 479-486.
15. Amit UP, Sunaullah B, Avupati RNS, Ganesh C, Nirmal KH, Krishna KM, Lakshmi K. 2022. Role of entomophily and artificial pollination in enhancing quality and yield of seed onion (*Allium cepa* L.) in Indian Himalayas. *Jr. Apic. Sci*. 66(2): 133-147.
16. Hoehn P, Tscharntke T, Tylianakis JM, Steffan-Dewenter I. 2008. Functional group diversity of bee pollinators increases crop yield. *Proc. R. Soc. B Biol. Science* 275(1648): 2283-2291.
17. Collier R. 2023. Pest insect management in vegetable crops grown outdoors in northern Europe – approaches at the bottom of the IPM pyramid. About Front. Hortic. 2.
18. Gagic V, Marcora A, Howie LJ. 2019. Additive and interactive effects of pollination and biological pest control on crop yield. *Jr. Appl. Ecology* 56(11): 2528-2535.
19. Hickman JM, Wratten SD. 1996. Use of *Phelia tanacetifolia* strips to enhance biological control of aphids by hoverfly larvae in cereal fields. *Jr. Econ. Entomology* 89(4): 832-840.
20. White AJ, Wratten SD, Berry NA, Weigmann U. 1995. Habitat manipulation to enhance biological control of brassica pests by hover flies (Diptera: Syrphidae). *Jr. Econ. Entomology* 88(5): 1171-1176.
21. Shrestha B, Finke DL, Piñero JC. 2019. The "botanical triad": The presence of insectary plants enhances natural enemy abundance on trap crop plants in an organic cabbage agro-ecosystem. *Insects* 10(6): 181.
22. Amoabeng BW, Johnson AC, Gurr GM, Gurr GM. 2019. Natural enemy enhancement and botanical insecticide source: a review of dual-use companion plants. *Appl. Entomol. Zoology* 54(1): 1-19.
23. Adelabu DB, Franke AC. 2023. Response of soil fertilization and insect pollination on okra production: Prospect for optimizing underutilized crop management. *Jr. Agric. Food Research* 14: 100869.
24. Basnett S, Krpan J, Espíndola A. 2024. Floral traits and their connection with pollinators and climate. *Ann. Botany*. pp 1-15.
25. Slavković F, Bendahmane A. 2023. Floral phytochemistry: Impact of volatile organic compounds and nectar secondary metabolites on pollinator behavior and health. *Chem. Biodivers* 20(4): e202201139.
26. Xiang G-J, Jiang Y, Lan J, Huang L, Liu Z, Xia J. 2023. Different influences of phylogenetically conserved and independent floral traits on plant functional specialization and pollination network structure. *Front. Plant Science* 14: 1084995.
27. Abbas F, Yu Y, Bendahmane M, Wang HC. 2023. Plant volatiles and color compounds: From biosynthesis to function. *Physiol. Plant* 175(3): 13947.
28. Palmer-Young EC, Farrell IW, Adler LS, Milano NJ, Egan PA, Junker RR, Irwin RE, Stevenson PC, Stevenson PC. 2019. Chemistry of floral rewards: Intra- and interspecific variability of nectar and pollen secondary metabolites across taxa. *Ecological Monographers* 89(1): e01335.
29. Rivera-Vega LJ, Grunseich JM, Aguirre NM, Valencia CU, Sword GA, Helms AM. 2022. A beneficial plant-associated fungus shifts the balance toward plant growth over resistance, increasing cucumber tolerance to root herbivory. *Plants* 11(3): 282.
30. Barber NA, Kiers ET, Theis N, Hazzard RV, Adler LS. 2013. Linking agricultural practices, mycorrhizal fungi, and traits mediating plant–insect interactions. *Ecol. Appl*. 23(7): 1519-1530.
31. Haghighi M, Mohmmadnia S, Pessarakli M. 2016. Effects of mycorrhiza colonization on growth, root exudates, antioxidant activity and photosynthesis trait of cucumber grown in Johnson modified nutrient solution. *Jr. Plant Nutr.* 9(14): 2079-2091.
32. Koricheva J, Gange AC, Jones T. 2009. Effects of mycorrhizal fungi on insect herbivores: A meta-analysis. *Ecology* 90(8): 2088-2097.
33. Bottero I, Dominik C, Albrecht M, Attridge E, Cini E, Costa C, De la Rúa P, de Miranda JR, Hodge S, Knauer AC, Mänd M, Martinez-Lopez V, Medrzycki P, Potts SG, Raimets R, Rundlöf M, Schwarz JM, Senapathi D, Tamburini G, Di Prisco G.

2023. Impact of landscape configuration and composition on pollinator communities across different European biogeographic regions. *Front. Ecol. Evolution* 11.
34. García-Feced C, Weissteiner CJ, Baraldi A, Paracchini ML, Maes J, Zulian G, Kempen M, Elbersen B, Pérez-Soba M. 2015. Semi-natural vegetation in agricultural land: European map and links to ecosystem service supply. *Agron. Sustain. Development* 35(1): 273-283.
35. Rivers-Moore J, Andrieu E, Vialatte A, Ouin A. 2020. Wooded semi-natural habitats complement permanent grasslands in supporting wild bee diversity in agricultural landscapes. *Insects* 11(11): 812.
36. Pfister SC. 2017. Potential of semi-natural habitats to support pest control and pollination—Including a case study on pumpkin. Retrieved from https://kola.opus.hbz-nrw.de/frontdoor/index/index/year/2017/docId/1476
37. Klein A-M, Brittain C, Hendrix SD, Thorp RW, Williams NM, Kremen C. 2012. Wild pollination services to California almond rely on semi-natural habitat. *Jr. Appl. Ecology* 49(3): 723-732.
38. Bihaly ÁD, Piross IS, Pellaton R, Szigeti V, Somay L, Vajna F, Soltész Z, Báldi A, Sárospataki M, Kovács-Hostyánszki A. 2024. Landscape-wide floral resource deficit enhances the importance of diverse wildflower plantings for pollinators in farmlands. *Agric. Ecosyst. Environ*. 367: 108984.
39. Walker E, Wooliver R, Russo L, Jagadamma S. 2024. The context-dependent benefits of organic farming on pollinator biodiversity: A meta-analysis. *Jr. Appl. Ecology* 62(1): 41-52.
40. Reddy NKS, Adhikari V, Tippimath S, Nagarjuna TN, Niranjana MV. 2024. Integrating insect dynamics in agricultural ecosystems: The role of predators, prey, and sustainable practices in enhancing biodiversity and ecosystem resilience. *Insect Environ*. 27(4): 458-466.
41. Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R, Carvalheiro LG, Chaplin-Kramer R, Gagic V, Garibaldi LA, Ghazoul J, Grab H, Jonsson M, Karp DS, Kennedy CM, Kleijn D, Kremen C, Landis DA, Zaragoza-Trello C. 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. *Bio-archive* 554170.
42. Sánchez AC, Jones SK, Purvis A, Estrada-Carmona N, De Palma A. 2022. Landscape complexity and functional groups moderate the effect of diversified farming on biodiversity: A global meta-analysis. *Agric. Ecosyst. Environ*. 332: 107933.
43. Martin EA, Dainese M, Clough Y, Báldi A, Bommarco R, Gagic V, Garratt MP, Holzschuh A, Kleijn D, Kovács-Hostyánszki A, Marini L. 2019. The interplay of landscape composition and configuration: New pathways to manage functional biodiversity and agroecosystem services across Europe. *Ecol. Letters* 22(7): 1083-1094.
44. Ammann L, Bosem-Baillod A, Herzog F, Frey D, Entling MH, Albrecht M. 2024. Spatio-temporal complementarity of floral resources sustains wild bee pollinators in agricultural landscapes. *Agric. Ecosyst. Environ*. 359: 108754.
45. Hyder M, Li Y, Raza MF, Zhang M, Chen J, Mao J, Bukero A, Zhang L. 2023. Enhancing *Coccinella* beetle biological pest control via a floral approach in cucumber greenhouse. *Life* 13(10): 2080.
46. De-Manincor N, Fisogni A, Rafferty NE. 2023. Warming of experimental plant-pollinator communities advances phenologies, alters traits, reduces interactions, and depresses reproduction. *Ecol. Letters* 26(2): 323-334.
47. Leclerc M, Gibernau M, Pincebourde S. 2024. Pollination-related plant traits under environmental changes: Seasonal and daily mismatches produce temporal constraints. *Funct. Ecol*. pp 1-11.
48. Ma G, Ma C, Le Lann C, van Baaren J. 2024. Effects of climate change on insect phenology. Oxford University Press. pp 89-110.
49. Hoover SE, Ladley JJ, Shchepetkina AA, Tisch M, Gieseg SP, Tylianakis JM. 2012. Warming, CO_2, and nitrogen deposition interactively affect a plant-pollinator mutualism. *Ecol. Letters* 15(3): 227-234.
50. Gambel J, Holway DA. 2024. Temperature and soil moisture manipulation yields evidence of drought-induced pollen limitation in bee-pollinated squash. *Ecol. Evol. Biol*. 14(6): e11400.
51. Skendžić S, Zovko M, Pajač Živković I, Lešić V, Lemić D. 2021. The impact of climate change on agricultural insect pests. *Insects* 12(5): 440.
52. Yadav S, Sarangi S, Shafi AA, Pandey KP, Thodusu M, Soni S, Parmar S. 2024. Climate change and insect ecology: Impacts on pest populations and biodiversity. *Jr. Adv. Microbiology* 24(12): 103-118.
53. Anonymous. 2023. Advances in Environmental Engineering and Green Technologies Book Series. pp 1-12.
54. Eigenbrode SD, Adhikari S. 2023. Climate change and managing insect pests and beneficials in agricultural systems. *Agronomy Journal* 115(5): 2194-2215.
55. Karthik CM, Biradar A, Prakash HT. 2024. Efficacy of some insecticides against fruit borer *Helicoverpa armigera* (Hübner) and two-spotted spider mite *Tetranychus urticae* (Koch) in tomato. *Indian Jr. Entomology*. pp 1-4.
56. Patidar RK, Tayde AR, Tak A. 2024. Efficacy of selected insecticides against tomato fruit borer, *Helicoverpa armigera* (Hubner) in tomato. *Jr. Exp. Agric. Int*. 46(7): 144-148.
57. Kumar S, Singh SK, Chandra U. 2024. Bio-efficacy of certain combination insecticides against insect pests in tomato. *Environ. Ecology* 42(3): 935-941.
58. Azizi MI, Danish W, Sharafat AR. 2024. Evaluation of different insecticides against fruit borer (*Helicoverpa armigera*) in tomatoes grown in Laghman, Afghanistan. *Eur. Jr. Theor. Appl. Science* 2(5): 286-295.
59. Prashanth G, N S, S C, V SK. 2024. Efficacy of diamide insecticides delivered through different methods against shoot and fruit borer *L. orbonalis*. *Jr. Adv. Biol. Biotechnology* 27(5): 292-302.
60. El-Ghanam A, Ekram AA, Esara S, Abdel-Aziz AA, El-Sarand E. 2024. Efficacy and residual analysis of three insecticides against *Spodoptera littoralis* (Boisd.) on field-grown tomatoes. *Asian Jr. Res. Crop Science* 9(4): 39-46.
61. Adusei S, Azupio S. 2022. Neem: A novel biocide for pest and disease control of plants. *Jr. Chemistry* 2022: 1-12.
62. Gurjar MK, Jat BL, Choudhary P, Kumar V. 2022. Bio-efficacy of newer insecticides and botanicals against red pumpkin beetle *Raphidopalpa foveicollis* (Lucas) on bottle gourd, *Lagenaria siceraria* (Molina) Stand. *Jr. Entomol. Res*. 46(3): 570-575.
63. James K, Springate S, Harte SJ, Farman DI, Colgan R, Arnold SEJ. 2024. How multi-species pollination boosts strawberry yield, quality, and nutritional value. *Jr. Pollinat. Ecology* 37: 326-340.