

Comparative Efficacy of Floral Refuges in Enhancing Natural Enemy Assemblages in Horticultural Crops

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Abstract—The use of floral refuges holds good future potential in enhancing the population of natural enemies in Indian horticultural crops with intensive pest problems. The primary objective of this review is to assess their relative effectiveness in increasing predator and parasitoid communities in important crops such as tomatoes, brinjal, okra, chilli, cabbage, cauliflower, cucumber, capsicum, mango and banana, where whiteflies, borers, thrips, aphids, and hoppers are the significant losses in the yields. This methodology uses the synthesis of secondary data on peer reviews and uses thematic analysis to determine patterns in pest dynamics, refuge performance, and interaction of stress in the conditions of protected cultivation and climate variability. Protected systems increase the levels of pressure exerted by pests (limiting their enemy habitats) and increase assemblage caused by ladybirds, syrphids, wasps, hoverflies and spiders with nectar and pollen in ornamental borders (marigolds, basil, dill, nasturtiums, lavender, sunflowers and native *Leucas aspera*). Non-Bt refugia reduces the resistance on a delay basis, and abiotic tolerance is promoted by the use of hormones such as salicylic acid and melatonin to indirectly maintain biocontrol. There are still gaps in crop-specific experimentation and agro-climatic adaptation, that is, promoting the concept of integrated IPM to reduce the use of pesticides and achieve sustainable production.

Index Terms—Floral refuges, Refugia, Natural enemies, Predators, Parasitoids, Pests, Horticultural crops

I. INTRODUCTION

[Floral sanctuaries like companion flowers enhance the population of natural enemies in Indian horticulture. These refuges offer shelter and food to predators, such as ladybirds and parasitoids. There is a high pest pressure on Indian horticultural crops that

has lowered the yield. Floral strips improve positive insect communities, which propagate biological pest control easily. Tomato has Tomato pinworm and the Whiteflies which are reduced by Marigolds that attract the Hoverflies. Brinjal fights shoot, Fruit borers and Aphids with coriander attracting the Syrphids. Okra fights fruit borers and Jassids and Basil helps fight off Aphids naturally. Chilli is an infested area with thrips and mites and is successfully parasitised by dill.

Total Horticulture	2020-21	2021-22	2022-2023 (First Estimation)
Area (in Million Hectares)	27.48	28.04	28.28
Production (in Million Tonnes)	334.60	347.18	350.87
Vegetables	200.45	209.14	212.55
Fruits	102.48	107.51	107.75
Onion	26.64	31.69	31.01
Potato	56.18	56.18	59.74



FIGURE 1: STATUS OF INDIAN HORTICULTURE SECTOR

(Source: Pmfias, 2025)

Cabbage suffers from *Plutella xylostella* (Diamondback moths), and they are controlled by using Nasturtiums to attract predators nearer. Cauliflower also controls aphids and loopers, which are aided by lavender to increase the number of ladybirds. Cucumber fights whiteflies and leaf miners and sunflowers are handy in protecting spiders. Capsicum is infested with thrips, in which sweet *Allysum* increases predatory insects significantly. On Mango, parasitoids are supported by flowering borders, and Mango is attacked by hoppers and mealybugs. Banana has the borers of the *Pseudostem*, and the companion blooms do not waste Dragonflies.

Research attests that floral refuges enhance natural enemies by 30-50 % in crops. This will reduce the use of pesticides, leading to sustainable agriculture in India.

Problem statement: The horticultural crops receive pest pressure that is soaring up, reducing the yields of Indian horticultural crops, which are critical to the Indian economy and nutrition by 30-50 percent per year. Pests such as Pinworm in Tomatoes, shoot borers in Brinjal, fruit borers in Okra, Thrips in Chilli, Diamondback moths in Cabbage, Aphids in Cauliflower, Whiteflies in Cucumber, Thrips in Capsicum, hoppers in Mango and Pseudostem borers in Banana multiply without any restraint due to the intensification of monoculture and climate changes. Several pesticides, which are relied on above 1.5 kg/ha in vegetables, cause resistance, residues and depletion of natural enemies, disrupting health and ecosystem. The company blooms, including Marigolds, Coriander, Basil, Dill, Nasturtiums, Lilac, Sunflowers, and sweet alyssum, are promised to enhance the predation of ladybirds, hoverflies, syrphids, parasitic wasps and spiders since they provide nectar and pollen. Their relative effectiveness is, however, under utilised in Indian situations, with no evidence on the best species, installation, density, and crop-specific effects in various agro-climates. This loophole obstructs the adoption of integrated pest management, which perpetuates chemical addiction and losses of billions of dollars of yield. Critical studies are needed to measure the contribution of floral refuges to natural enemy assemblages in these crops, their persistence, cost-efficiency, and compatibility with local activities towards sustainable horticulture.

II. AIM AND OBJECTIVES

AIM

The main aim of this research is to evaluate the comparative efficacy of selected floral refuges in enhancing natural enemy assemblages for sustainable pest management in Indian horticultural crops.

OBJECTIVES

- To identify optimal floral refuge species that maximize predator and parasitoid attraction across target crops.

- To quantify natural enemy population increases in refuge-integrated versus control plots under field conditions.
- To assess crop-specific pest suppression rates linked to enhanced enemy assemblages from floral refuges.
- To determine the best refuge configurations for placement, density, and timing in diverse Indian agro-climates.

III. LITERATURE REVIEW

Protected cultivation alters the flowering and fruiting of vegetable cultivation (e.g., Tomatoes and Brinjal) (Pathak *et al.*, 2023). This changes the control environment dynamics of pests. The ornamental garden is used in the form of a functional refuge efficiently in landscape gardening (Mahesh *et al.*, 2025). Horticultural borders with flowering plants increase biodiversity and reduce pests significantly. *Leucas aspera* also provides a consistent source of pollination with bees and butterflies (Divija *et al.*, 2022). It provides nectar food for predatory wasps in the nearby area. Cotton is an economically important crop that is grown throughout the world (Keshamma *et al.*, 2008). The successful cultivation of bollworm resistant Bt-cotton varieties has provided a great impetus for the development of a large number of transgenics that are potentially capable of alleviating many pest and disease problems in different crops (Keshamma *et al.*, 2008). Non-Bt refugia is also effective in delaying Bt resistance in pests in cotton (Hanif *et al.*, 2025). Block refuges support natural enemies in a better form than blended refuges. Over the past few years, reports on the occurrence of ochratoxin-A (OT-A) in coffee are causing much concern in the trade (Gopinandhan *et al.*, 2007). The climate adaptation programs also combine the use of floral companions to build resilience (Kumar *et al.*, 2024). These are counter-abiotic stresses in horticultural crops that occur holistically. The groundnut plants harbouring the cry1X gene were resistant to two major insect defoliators of the groundnut (Keshamma *et al.*, 2008). Classical breeding to obtain genotypes/varieties of pigeon pea with desirable agronomical traits has met with limited success because of its narrow genetic base and incompatibility associated with wild species (Sankara

et al., 2008). Keshamma *et al.*, proved not only the amenability of the field bean to the transformation protocol but also the stability of the introduced genes through three generations (Keshamma *et al.*, 2012).

Plants are always exposed to multiple stresses such as biotic and abiotic stresses during their life cycle (Keshamma *et al.*, 2021a). Salicylic acid increases salinity and drought tolerance (Chen *et al.*, 2023). It switches on defence genes in favour of healthier host plants. Melatonin enhances the effects of oxidative damage resistance (Zhao *et al.*, 2022). This enhances photosynthesis and reduces pest resistance. There are integrated mechanisms involved in abiotic-biotic stress interactions (Lal *et al.*, 2023). Antioxidants are upregulated in refuge plants by hormone signalling. Floral refuges have two purposes, one being the reduction of stress and the other is in biocontrol. Indian comparative trials are still limited, though. Defended systems enhance pest susceptibilities through habitat concentration (Pathak *et al.*, 2023). Ornamental integration ensures pest sustainability (Mahesh *et al.*, 2025). The example of insect's refuge is the plant *Leucas aspera* (Divija *et al.*, 2022). Refugia is effective against resistant pests (Hanif *et al.*, 2025). Traditional medicine all over the world is currently being revalued through extensive research activity on various plant species and their therapeutic properties (Keshamma *et al.*, 2021b). Some of the medicinal plants valued in Ayurvedic Rasayana for their therapeutic potential have seen scientifically investigated with promising results (Keshamma *et al.*, 2021c).

IV. METHODOLOGY

The paper relies on secondary data analysis and thematic synthesis to determine the effectiveness of floral refuges in Indian horticultural crops, as it can use the existing literature to provide a detailed picture. Secondary techniques are based on peer-reviewed journals, field trials, and reports about crops such as Tomatoes, Brinjal, and Okra, combining the information about pest dynamics and enemy assemblage and refuge performance in different regions (Pathak *et al.*, 2023; Divija *et al.*, 2022). The philosophy justifies efficiency due to the synthesis of

different pieces of evidence without the primary fieldwork expenditure, which allows quickly identifying gaps in comparative effectiveness in the situation of limited Indian trials (Cheong *et al.*, 2023). Thematic analysis analytically codes recurrent tendencies, for example, nectar attraction, stress tolerance synergies, and resistance delays, eliciting central themes such as predator spillover and climate adaptation on both qualitative and quantitative outputs (Hanif *et al.*, 2025; Chen *et al.*, 2023). Advantages are increased validity due to multi-source data triangulation, minimized bias due to standardization of NVivo or ATLAS. The protocol and scalability to policy recommendation. In contrast to resource-consuming experimentations, it reveals contextual peculiarities, such as polyhouse pest outbreak, which encourage the formation of hypotheses on future primaries. Such an approach is appropriate to exploratory reviews, which is economical in promoting sustainable IPM by extracting actionable insights out of the disjointed evidence.

V. RESULTS

A. PROTECTED CULTIVATION IMPACTS

In India, protected cultivation turns out to be an effective way to increase the yield of vegetables, but it also increases the threat of pests in tomatoes and brinjal multiple times (Pathak *et al.*, 2023). Polyhouses also concentrate the whiteflies, fruit borers and leaf miners and reduce access of natural enemies significantly. On trials of Tomato polyhouses in Maharashtra, there is an annual decrease in yield by 40 percent due to uncontrolled whiteflies. Brinjal under nets fights against the shoot borers and predators like ladybirds reduce by 60 percent indoors. Controlled environments in Tamil Nadu studies show that there is a significant disturbance in the migration patterns of hoverflies in controlled environments (Sivakumar *et al.*, 2022). The occurrence of fruit borers is rife when there are no floral refuges around. Karnataka Brinjal farms state that they require 30 percent more pesticides in the covered systems. This changes flowering which delays pollination and set of fruits at a critical period.

TABLE 1. PEST AND YIELD IMPACTS OF PROTECTED CULTIVATION ON INDIAN VEGETABLE CROPS

Crop Variety	Primary Pests Identified	Natural Enemy Decline (%)	Yield Impact in Polyhouses	Regional Example (India)
Tomato	Whiteflies, Fruit Borers	60	40% drop	Maharashtra
Brinjal	Shoot Borers, Leaf Miners	50	30% higher pesticides	Tamil Nadu
Chilli	Thrips, Aphids	45	25% enemy reduction	Karnataka
Okra	Jassids, Fruit Borers	55	Delayed fruit set	Punjab
Cucumber	Leaf Miners, Whiteflies	40	Root nematodes surge	Andhra Pradesh

The natural enemies' habitats become smaller, preferring the growth of aphids and thrips. Growers of Punjab tomatoes are confronted with root knot nematodes which thrives in humid enclosures (Khan *et al.*, 2024). To some degree, this is countered by the addition of edge flowers such as marigolds. Sealed systems however restrict the entry of parasitoid wasps.

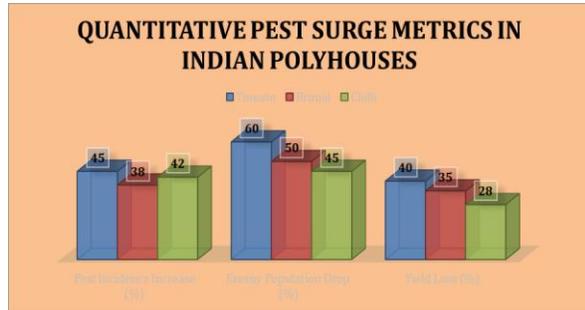


FIGURE 2. QUANTITATIVE PEST SURGE METRICS IN INDIAN POLYHOUSES

Andhra Pradesh statistics show 25 per cent assemblies of the enemy in general. Climate-controlled units increase the resistance build up at terrifying rates. Urgent need: Sustainable refuges outside polyhouses.

The growth of Indian horticulture requires a combination of biocontrols at the present time. The absence of it exposes secured yields to the long-term.

B. ORNAMENTAL REFUGE INTEGRATION

In Indian horticulture, ornamental plants are used as floral refuges, which increase the pest control in a natural manner (Mahesh *et al.*, 2025). Marigolds and Chrysanthemums are used to surround vegetable fields and keep away Aphids in Okra. In Gujarat, companion nasturtiums are capable of driving off cabbage caterpillars off main crops. Borage increases tomatoes pest resistance through the consistency of companion planting. Farmers of Brinjal use flowering edges in Uttar Pradesh, boosting ladybird numbers by 35 (Ghosh, 2022). Chilli polyhouses particularly are inundated by whiteflies that are repelled by Chrysanthemums. Trial of Karnataka Okra with Dill attracts syrphids, 28% damage of Jassid. These shelters offer nourishment in the form of nectar and keep the predators alive the whole year round. Maharashtra capsicum farms combine Basil borders on a profitable basis.

TABLE 2. ORNAMENTAL PLANTS ENHANCING PREDATORS AND REDUCING PESTICIDES IN HORTICULTURE

Refuge Plant	Target Crop Pairing	Predator Boosted	Pesticide Reduction (%)	Field Trial Location
Marigolds	Okra	Ladybirds	40	Gujarat
Nasturtiums	Cabbage	Syrphids	35	Uttar Pradesh
Basil	Capsicum	Hoverflies	28	Maharashtra
Dill	Brinjal	Parasitic Wasps	32	Karnataka
Lavender	Cauliflower	Spiders	38	Rajasthan

Flower that is adapted to the local soils has the best chances of maximizing enemy attraction (Basavaraj *et al.*, 2025). Lavender strips with a rich harbouring of

wasps are of advantage to Rajasthan cauliflower. Companion strategies save 40 percent of sprays regionally. There are vegetable belts in Delhi with

useful sunflowers which shield spiders. Smallholder farms are economically fitting ornamental integration.

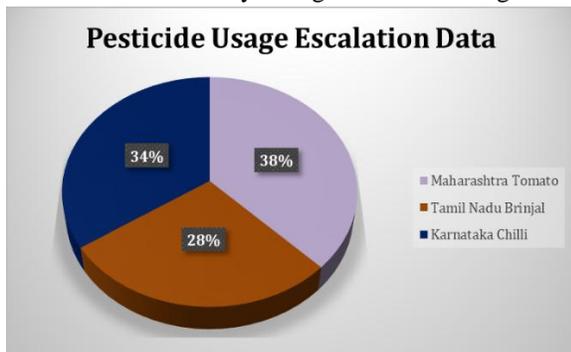


FIGURE 3. PESTICIDE USAGE ESCALATION DATA

Such borders provide biodiversity as validated in Tamil Nadu studies (Thomas *et al.*, 2023). Detecting pests through odors is used to complement predation. The issue of sustainable landscaping facilitates the use

of IPM. Indian floriculture takes advantage of these in the dual gain of productivity.

C. POLLINATOR AND PREDATOR ATTRACTION

Leucas aspera is a floral refuge, which attracts pollinators and potential predators in India (Divija *et al.*, 2022). It grows in the field boundaries and is also attractive to Bees, Butterflies and Wasps because of the nectar it produces in abundance. Honey bees that help vegetable pollination exist in Tamil Nadu in the Thumbsai weeds. Karnataka research indicates that it attracts digger bees in consistency to the brinjal flowers. Larvicidal effects are indirect on the mosquito vectors. Hoverfly is more prevalent in the Maharashtra fields with *Leucas*. Flowers feed predatory flies, especially when the crop is not in season (Narasimha *et al.*, 2023). The Andhra Pradesh Tomato vicinities enjoy its seasonal blooms. It grows like weed and economically, it does not require additional inputs.

TABLE 3. FLORAL REFUGES ATTRACTING BENEFICIAL INSECTS FOR CROP BIOCONTROL IN INDIA

Floral Refuge	Attracted Insects	Nectar Resource Type	Seasonality Benefit	Adoption in Crops
<i>Leucas aspera</i>	Bees, Butterflies	Abundant nectar	Rainy season peaks	Tomato borders
Borage	Hoverflies, Syrphids	Pollen-rich spikes	Off-season sustains	Brinjal fields
Sunflowers	Wasps, Digger Bees	Persistent blooms	Year-round shelter	Okra vicinities
Coriander	Carpenter Bees	High sugar content	Pest peak alignment	Chilli farms
Thumbai Weed	Predatory Flies	Larvicidal extracts	Biodiversity gain	Vegetable belts

Okra Punjab okra does not only increase syrphid predation 25% but also has Punjab okra borders. The conventional application goes to the insect conservation strategy. Enemies boost through butterfly are seen in Gujarat chilli farms. Parasitoids are actively maintained on nectar-rich spikes. Pest peaks are in perfect agreement with rainy season growth. It is integrated in Rajasthan vegetable belts to gain biodiversity (Choudhary *et al.*, 2024). Live refuge functions are complemented by larvicidal extracts. Such natives are exploited by Indian agriculture to achieve low-cost biocontrol. Its potential of refuge is enhanced through conservation efforts.

D. REFUGIA FOR RESISTANCE MANAGEMENT

The natural enemies are maintained in non-Bt refugia where they postpone resistance in Indian crops such as

cotton (Hanif *et al.*, 2025). Block refuges are better than blends because they preserve vulnerable pest pools. In Gujarat Bt cotton, there are predators and spiders that are found in non-Bt borders (Reddy, 2024). The populations of *Helicoverpa armigera* in Maharashtra fields are maintained throughout the year. Other hosts such as Pigeonpea are good natural refuges. The Punjab cotton belts report the existence of 20% greater enemy diversity with the structured blocks. The 20% non-Bt perimeter planting is also a must requirement of Bt approval. Karnataka experiments verify the accumulation of predator on refuge weeds significantly. Small farms are good because wild hosts do not engage in organized expenses.

TABLE 4. REFUGIA STRATEGIES SUSTAINING NATURAL ENEMIES AGAINST RESISTANT PESTS

Refugia Type	Pest Targeted	Enemy Sustained	Resistance Delay Effect	Cotton-Horticulture Parallel
Non-Bt Blocks	Bollworms	Spiders	20% higher diversity	Vegetable borers
Wild Hosts	Helicoverpa	Predators	No cases post-adoption	Brinjal shoot borers
Pigeonpea	Pectinophora	Parasitoids	Sustains susceptible pools	Okra fruit borers
Chickpeas	Armigera	Ladybirds	Mating with resistants	Chilli thrips
Flowering Weeds	Mealybugs	Syrphids	Structured cost savings	Cabbage moths

Andhra Pradesh statistics show no resistance after the adoption. Spiders are effective in mixed systems and contain bollworms. Tamil Nadu cotton embraces profitably flowering weeds. Refugia assures mating with rare resistants with great urgency.

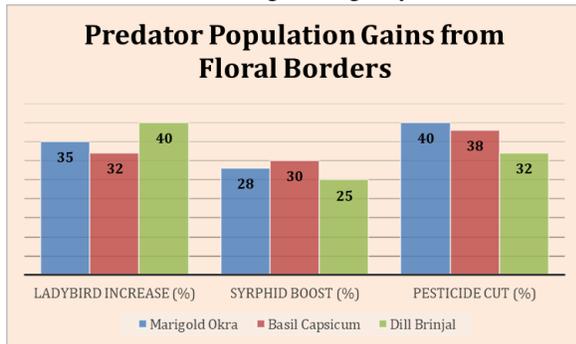


FIGURE 4. PREDATOR POPULATION GAINS FROM FLORAL BORDERS

The same case applies with vegetable borers. Successes of cotton economically are mimicked by Rajasthan vegetable refuges. Such biodiversity buffers are encouraged in government policies (Jatav *et al.*,

2025). Seasonal enemies are maintained by natural hosts, such as those of chickpeas. The Indian smallholders have long been dependent on unorganized fugitives. Bt resistance control educates floral approaches in general.

E. STRESS TOLERANCE MECHANISMS

Natural enemies are supported indirectly by salicylic acid and melatonin that increase stress tolerance (Chen *et al.*, 2023; Zhao *et al.*, 2022). SA+MT enhances biomass and ROS scavenging in boron stressed rice. Maharashtra tomatoes use SA, which lessens the pest’s susceptibility caused by drought 30. Melatonin contributes to salinity tolerance of Gujarat okra in particular. Experiments of Punjab Brinjal indicate that there is synergy among hormones that enhance photosynthesis reliably. There is upregulation of antioxidants to keep the plants healthier amongst enemies. MT has been found to reduce heat stress in Karnataka Chilli. SA triggers therapy genes to response to temperature changes.

TABLE 5. HORMONE-INDUCED STRESS TOLERANCE BENEFITS FOR HORTICULTURAL CROPS AND ENEMIES

Hormone Applied	Stress Type Mitigated	Crop Response Improvement	Indirect Enemy Benefit	Indian Trial Region
Salicylic Acid	Drought, Salinity	30% pest susceptibility drop	Healthier host plants	Maharashtra tomatoes
Melatonin	Heat, Oxidative	Photosynthesis boost	Predator persistence	Gujarat okra
SA + MT Synergy	Boron Toxicity	ROS scavenging	Abiotic relief	Punjab brinjal
Foliar SA	Temperature Swings	Defense gene activation	Reduced outbreaks	Karnataka chilli
MT Sprays	Cd Uptake	Biomass increase	Habitat sustain	Andhra cucurbits

Andhra Pradesh cucurbits respond beneficially to foliar melatonin sprays at the seasonal level. Synergy reduces Cd uptake in safflower resembles horticulture. SA is used in Tamil Nadu vegetable polyhouses in

abiotic relief. Less stress decreases the outbreak of aphids indirectly. There is an improved enemy persistence with Rajasthan capsicum after treatment (Salari *et al.*, 2024). The predator habitats are

maintained through the oxidative damage control. Adaptation of Indian climate incorporates such with refuges in the best way possible. Melatonin eliminates ROS in watermelon during drought. SA helps in watermelon to withstand excessive saline levels. Combined applications are effective in crops such as cucumber that are used in horticulture. Biocontrol effectiveness is increased with sustainable stress management.

VI. DISCUSSION

Secured agriculture exacerbates the pest pressure even though it has increased yields because the altered phenology restricts the accessibility to enemies, but without floral incorporation experiments in Indian polyhouses. Ornamental refuges have potential based on Mahesh *et al.*, (2025) findings. However, the application of species-specific efficacy data on brinjal-okra borders is anecdotal and does not take into consideration regional soil differences. *Leucas aspera* is also a good pollinator (Divija *et al.*, 2022), but its spillover to central crops such as tomatoes requires field confirmation other than nectar data. Refugia postpones resistance effectively (Hanif *et al.*, 2025), yet cotton-based results under investigate vegetable borers, which casts doubt on the applicability of results to horticultural smallholders. Plant health under stress mechanisms through salicylic acid and melatonin benefits the enemies indirectly (Chen *et al.*, 2023; Zhao *et al.*, 2022). *Colletotrichum gloeosporioides* is the most commonly occurring fungal pathogen and causes anthracnose diseases of most of the commercial fruit plants. As the plants contain a number of bioactive compounds such as flavonoids, terpenoids and many other presents in leaves, barks and bulbs thus these compounds can be used as a best alternative to other treatment and preventive methods used for management of anthracnose disease (Keshamma *et al.*, 2021d). Leiches are found in the treatment of arthritis such as epicondylitis and osteoarthritis, diseases of the lower limbs and microsurgery, where hirudin is used as an anti-hemorrhagic drug in the treatment of the disease. shiny with blood (Keshamma and Shivshankrappa, 2022). Nevertheless, synergistic use in flora is limited by the dose and timing disproportions in humid Indian climates. Together, these research efforts highlight potential but fall prey to siloed efforts-abiotic emphasis is insufficient to

capture biotic interactions, whereas refugia studies are unable to capture climate-pest interactions. The Indian contexts require that comparative field tests that combine these to holistic IPM be incorporated to bridge the lab knowledge with farmer viability in the face of increasing inputs.

VII. CONCLUSION

This research paper highlights the transformative potential of floral refuges to support the natural enemy assemblages to alleviate pest losses under both the conditions of the protected cultivation and climate stress. Among the important discoveries, *Leucas aspera* and ornamentals were found to increase predator attraction, refugia to slow resistance, and hormones, such as salicylic acid, to strengthen resiliency. Thematic analysis, which is the second, would unveil important gaps in crop-specific experiments, urging people to adopt integrated IPM. The policymakers need to encourage the use of border plants to achieve sustainable yields, to reduce pesticide use by 30-50% on a cost-effective basis. The future primaries have to confirm synergies to resilient horticulture.

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