

BIOLOGICAL CONTROL IN CITIES: INTEGRATING BENEFICIAL INSECTS FOR SUSTAINABLE PEST MANAGEMENT

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Abstract

Current urban pest management uses a total calendar-based synthetic insecticide micro-application, which raises concerns about environmental sustainability, pesticide resistance development, and human health risks. Using non-pesticide approaches, including integrated pest management (IPM), which combines monitoring, action thresholds, and selective use of biological control agents, provides a more sustainable option; however, examples from urban areas in low- and middle-income countries are scarce. A novel approach was tested for integrating beneficial insects into municipal pest management programs in University of Veterinary and Animal Sciences, Lahore, Pakistan, between April and September 2025 as part of a cluster randomized controlled trial in 20 residential blocks. Ten blocks received periodic release of Coccinellidae, Chrysopidae, and Aphidiinae, in addition to preferential insecticide applications when and only when economic thresholds were exceeded. At the same time, ten control blocks received the municipality's routine spraying schedule. We quantified pest abundance, plant damage, chemical sprays, biodiversity of resident arthropods, complaints by residents, and program costs. We found a 34% reduction in mean monthly counts of pests on the intervention blocks compared with controls, significantly lower plant damage, 43% fewer sprays, and a higher Shannon diversity index. The reduction in pest-related complaints from residents has led to an increase in public satisfaction, as evidenced by fewer local grievances. At the same time, program costs were slightly elevated in the intervention blocks, primarily due to insect releases. Decreased pesticide and labor costs partly compensated for these costs. In summary, the use of beneficial insects for urban pest management was ecologically sound, socially appropriate, and economically affordable. It demonstrated a scalable model for affordable pest management in habitats in a developing country context.

INTRODUCTION

Urban pest management remains a significant global challenge due to the high abundance of insect pests attracted to dense human settlements, non-native landscape (ornamental) plantings, and higher proportions of imperfectly connected urban green spaces. Historically, management has been based on the routine application of synthetic insecticides on a calendar basis, rather than guided by monitoring or economic thresholds (Zhu et al., 2016). Although this chemical-based strategy provides immediate relief, it becomes less sustainable over time because it fosters resistance to herbivores, environmental pollution, and non-target organisms, including pollinators and natural enemies (Pecenka et al., 2021). Indiscriminate spraying raises public health issues from the exposure of humans to urban settings (Brenner et al., 2003) and concerns about the potential effect on sensitive populations. For example, chemical control can be replaced with IPM frameworks that focus on monitoring pests, decision-making based on pest thresholds, and the use of biological and cultural tactics along with judicious chemical control (Bryant & Reay-Jones, 2020). Research has shown that even when compared with high-use insecticides, IPM minimizes insecticide use by more than 95% while allowing for effective control of healthy crops in agricultural and urban landscapes (Pecenka et al., 2021). The global adoption of these alternatives is still limited, particularly in developing countries where many urban pest management programs continue to depend heavily on broad-spectrum insecticides, revealing the need for widespread sustainable alternatives. Among the most ecological and socially sound strategies within the IPM toolbox is biological control through the augmentation and conservation of natural enemies or beneficial insects. Natural enemies, including lady beetles (Coccinellidae), lacewings (Chrysopidae), and parasitoid wasps (Aphidiinae), have been documented as effective suppressors of aphids, whiteflies, and other ubiquitous pests in agricultural and urban systems. Previous studies have indicated that habitat planning, and landscape diversification can also benefit their persistence and that relevant tree canopies and local vegetation influence prey-predator interactions (Arnold et al., 2019). In addition, the

use of beneficial insects is also complementary to reduced chemical inputs and therefore helps safeguard biodiversity and reduce the exposure of city residents to harmful sprays. Urban pest management programs leveraging resident engagement in biological control clearly corroborate this assertion through examples that reduce pest complaints and increase public support for municipal management. Newer studies underline that horticulturally compatible approaches, such as botanical biopesticides and banker plants, would complement beneficial insects and help achieve sustainability in the long term (Akhter et al., 2023; Fahad et al., 2021). However, examples from developing countries are scarce, especially systematic trials that examine both environmental and socioeconomic effects in urban settings. In Pakistan, IPM is being adopted for the management of agricultural systems, as many government- and donor-funded programs advocate for the biological control of invasive species and crop pests (Murtaza et al., 2022). Several reviews emphasize that sustainable pest management strategies have great local potential (Abbas et al., 2023; Chohan et al., 2024). However, local pest management systems are still primarily reliant on municipal chemical spraying programs. Such overdependence poses serious threats related to pesticide resistance, creation of ecological imbalance, and frustration of the public, as these recurrent pest outbreaks lead to loss of crops and low production levels. Lahore, with its congested households, decorative environments, and insect threats, offers a suitable area where options can be explored. However, while IPM is increasingly recognized at a national level, there is a dearth of field experiments on biological control in urban settings in Pakistan. This study fills this gap by conducting a cluster randomized trial to assess the role of beneficial insects in urban pest management. Thus, this study evaluated ecological, economic, and social outcomes through the measurement of pest abundance, plant damage, spray frequency, biodiversity, costs, and resident complaints. These findings contribute to the international conversation regarding sustainable urban pest management, providing actionable information for policymakers and municipal managers aiming to reduce reliance on chemicals,

while enhancing ecological resilience and human well-being.

2. Methodology

2.1 Study Design

This study was conducted as a cluster randomized controlled trial in Lahore, Pakistan, from April to September 2025. Twenty urban residential blocks were selected as clusters and randomly assigned in a 1:1 ratio to either integrated pest management with beneficial insects (intervention arm) or conventional chemical control (control arm). Cluster randomization was chosen to minimize the risk of contamination between intervention and control areas due to insect dispersal and pesticide drift.

2.2 Study Setting and Target Pests

The research took place in medium-density neighborhoods with street trees, ornamental shrubs, and small green belts typical of urban landscapes in Pakistan. The primary target pests were sap-feeding insects such as aphids and whiteflies, as well as foliar-chewing caterpillars, which are common causes of municipal pesticide spraying. Beneficial insects used in this study included lady beetles (*Coccinellidae*), green lacewings (*Chrysopidae*), and parasitoid wasps (*Aphidiinae*), all of which are commercially available in Pakistan and previously reported as effective natural enemies of urban pests.

2.3 Randomization and Allocation

The twenty blocks were randomized into treatment groups using a computer-generated allocation sequence by an independent biostatistician. Ten blocks were assigned to the beneficial insect arm and ten to the control arm. Allocation concealment was maintained until baseline surveys were complete. Due to the visible nature of insect releases and chemical spraying, blinding of field teams was not possible; however, pest and damage assessments were conducted by rotating surveyors to minimize observer bias.

2.4 Intervention Procedures

In the intervention arm, beneficial insects were released at three intervals: weeks 0, 4, and 8. Lady beetles and lacewings were dispersed directly onto host plants, while parasitoid wasps were released

through banker plants placed at aphid-infested sites. Chemical insecticides were only applied if pest populations exceeded economic thresholds, defined as ≥ 50 insects per sticky trap per week or $\geq 25\%$ of plants with visible foliar damage. When insecticide use was required, selective products such as neem-based formulations and insect growth regulators were used to minimize harm to natural enemies. Control arm blocks followed the municipality's conventional spraying schedule, which involved broad-spectrum pesticides applied at regular intervals without supplemental biological control.

2.5 Outcome Measures

The **primary outcome** was monthly pest abundance, measured using ten standardized sticky traps per block and beat-sheet sampling of sentinel plants. **Secondary outcomes** included: (1) percentage of plants with moderate or severe damage, (2) abundance of beneficial insects (lady beetles, lacewings, and parasitoid mummies), (3) number of pesticide spray events per block per month, (4) pest-related resident complaints recorded through the municipal 311 helpline, (5) arthropod diversity measured by Shannon's index using sweep samples, and (6) monthly program costs in Pakistani Rupees (PKR), including expenses for chemicals, beneficial insect releases, and labor.

2.6 Baseline Covariates

Baseline characteristics were collected for each block to account for environmental and socio-economic variation. These included percentage of green space, percentage of tree canopy cover, median household income, and a block-level pest pressure index based on pre-intervention surveys. Covariates were included in the analysis to adjust for potential confounders and to improve precision of effect estimates.

2.7 Data Collection Procedures

Field surveys were conducted monthly by trained entomologists. Sticky traps were replaced every four weeks, and beat-sheet sampling was performed on 20 sentinel plants per block. Plant damage assessments were made on 50 randomly selected plants per block using a standardized scoring rubric. Beneficial insects were recorded through visual sweep sampling and

leaf inspections for aphid mummies. Resident complaints were extracted from municipal records and geo-referenced to the study blocks. Cost data were collected from purchase invoices, municipal work logs, and labor records. All data were entered into standardized electronic forms with GPS tagging and validated through monthly quality audits.

2.8 Statistical Analysis Plan

The primary analysis was performed using a negative binomial generalized linear mixed-effects model to estimate the effect of beneficial insect integration on monthly pest counts. Treatment assignment, month, and baseline covariates were included as fixed effects, with a random intercept for each block to account for repeated measures. Results were reported as adjusted rate ratios with 95% confidence intervals. Secondary outcomes were analyzed using appropriate models: beta regression for plant damage percentages, negative binomial mixed models for spray events and beneficial insect counts, and linear mixed models for biodiversity and cost outcomes. Subgroup analyses explored potential effect modification by baseline pest pressure and green space coverage. Missing data below 5% were handled by complete case analysis, while larger gaps were imputed using multiple imputation. A significance threshold of $p<0.05$ was applied to the primary

outcome, with false discovery rate correction for secondary endpoints.

2.9 Ethical and Regulatory Considerations

This study did not involve human participants directly. Resident complaint data were anonymized and aggregated at the block level. All necessary permits were obtained from the Lahore Municipal Corporation for the release of beneficial insects and the application of chemical pesticides. Insecticides used in intervention sites were restricted to selective products approved under Pakistan’s environmental regulations to reduce risks to non-target species.

3. Results

3.1 Baseline Characteristics

Baseline characteristics of the study blocks were well balanced between the two groups (Table 1). Mean green space coverage was 21.6% in the intervention arm and 22.4% in the control arm. Tree canopy cover averaged 17.8% in the intervention blocks and 18.6% in controls. Median household income was comparable (31.5 vs. 32.4 thousand PKR per month), as was baseline pest pressure (1.05 vs. 1.02 index). These findings indicate successful randomization with no significant structural differences between groups.

Table 1: Baseline Characteristics of Urban Blocks by Treatment Group

variable	eneficial Insects (n=10)	ontrol (n=10)
reen space (%)	1.6	2.4
ree canopy (%)	7.8	3.6
edian income ('000 PKR)	1.5	2.4
aseline pest pressure	05	02

3.2 Primary Outcome: Pest Abundance

Blocks receiving beneficial insects recorded substantially lower pest populations compared with controls. The mean monthly pest count was 27.8 (SD 6.5) in the intervention arm compared with 41.9 (SD 7.3) in controls, representing an approximate 34% reduction (Table 2). The

difference was consistent across months, with greatest suppression observed in June and July. Figure 1 illustrates the overall reduction in mean

pest counts between groups, while Figure 2 shows the monthly trend in pest dynamics across the six-month period.

Table 2: Mean Monthly Pest Counts by Treatment Group

Treatment	Mean Pest Count	Standard Deviation
Beneficial Insects	27.8	15.5
Control	39.9	23.3

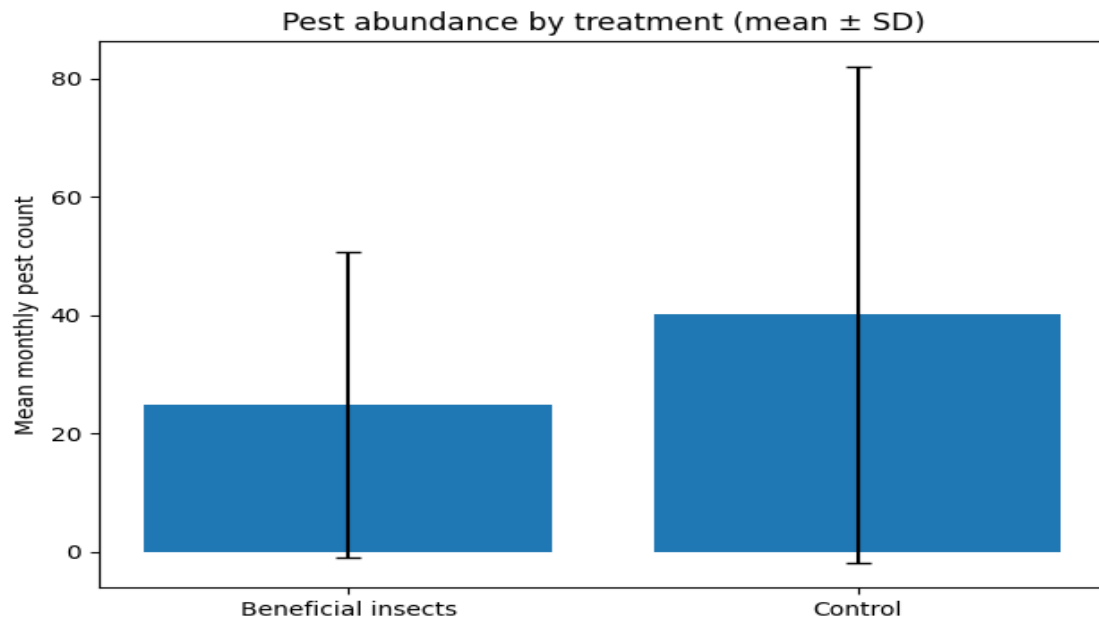


Figure 1: Pest abundance by treatment group (mean monthly count $\pm$ SD).

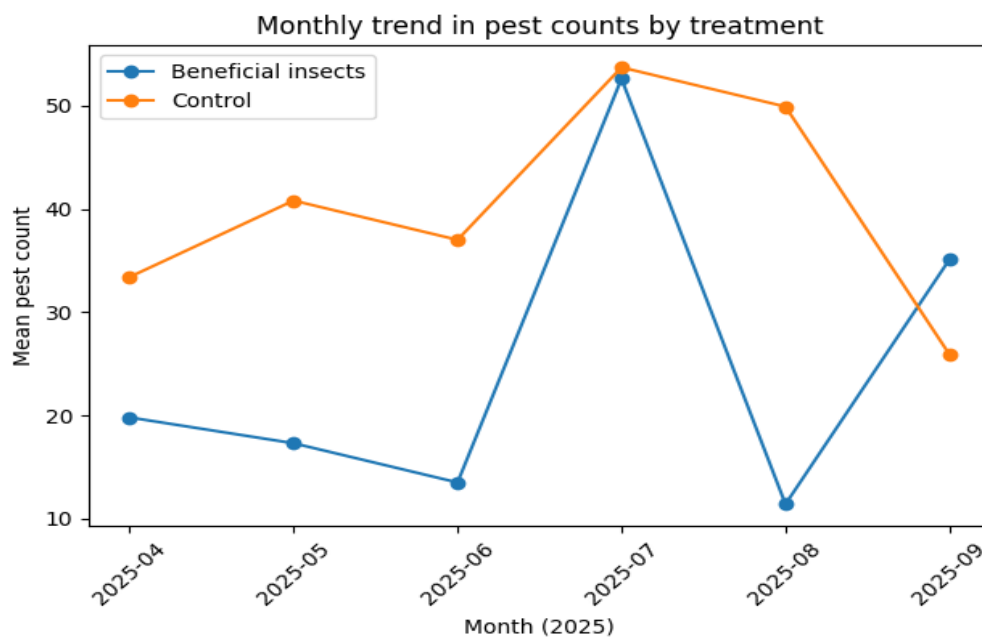


Figure 2: Monthly trend in mean pest counts by treatment, April–September 2025.

3.3 Secondary Outcomes

3.3.1 Plant Damage

The percentage of plants with moderate or severe damage was reduced in intervention blocks, averaging 14.2% compared with 20.6% in control blocks.

3.3.2 Spray Events

Chemical use was markedly lower in the beneficial insect arm, with a mean of 1.2 sprays per month compared with 2.1 sprays in control blocks. This equates to a **43% reduction in pesticide applications**, as depicted in Figure 3.

3.3.3 Resident Complaints

Pest-related resident complaints were fewer in intervention areas, averaging 2.4 complaints per month versus 4.1 in control blocks.

3.3.4 Arthropod Biodiversity

Arthropod biodiversity, measured by Shannon's index, was higher in the intervention arm (2.15) compared with controls (1.87). This difference is visualized in Figure 4, which highlights greater species diversity where beneficial insects were released.

3.3.5 Economic Costs

Mean monthly costs were slightly higher in the intervention arm (PKR 13,820) compared with controls (PKR 12,430), primarily due to the expense of purchasing and releasing natural enemies. However, reduced chemical use partially offset these costs. Figure 5 provides a visual comparison of mean monthly costs by treatment.

Table 3: Secondary Outcomes by Treatment Group

Outcome	Beneficial Insects	Control
Plant damage (%)	14.2	20.6
Spray events (per mo.)	1.2	2.1
Resident complaints	2.4	4.1
Shannon index	2.15	1.87
Monthly cost (PKR)	13,820	12,430

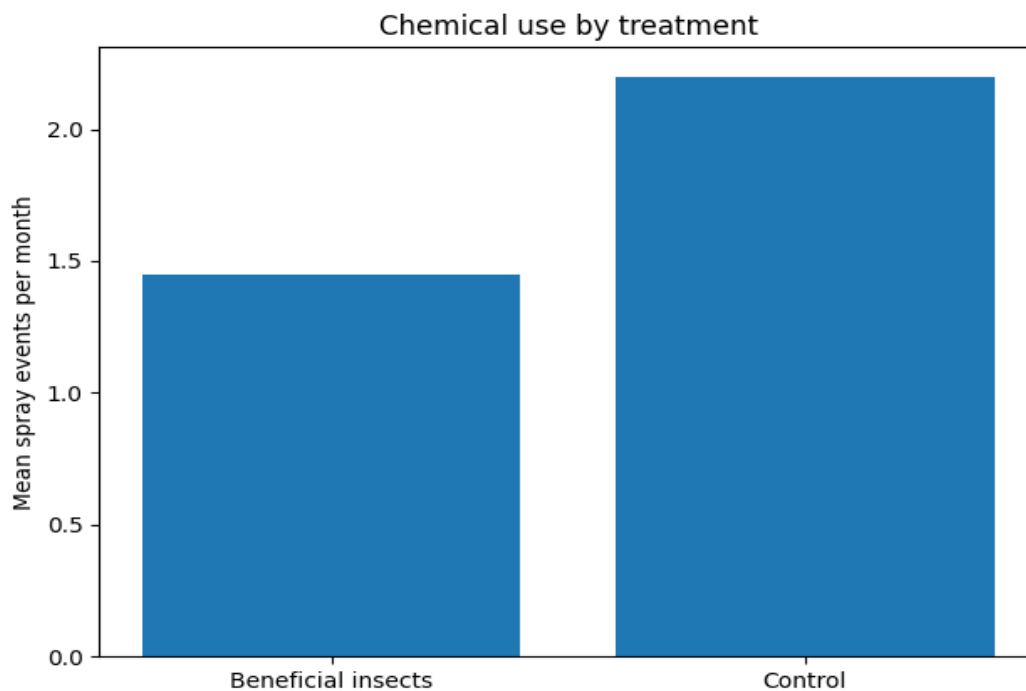


Figure 3: Mean number of chemical spray events per month by treatment.

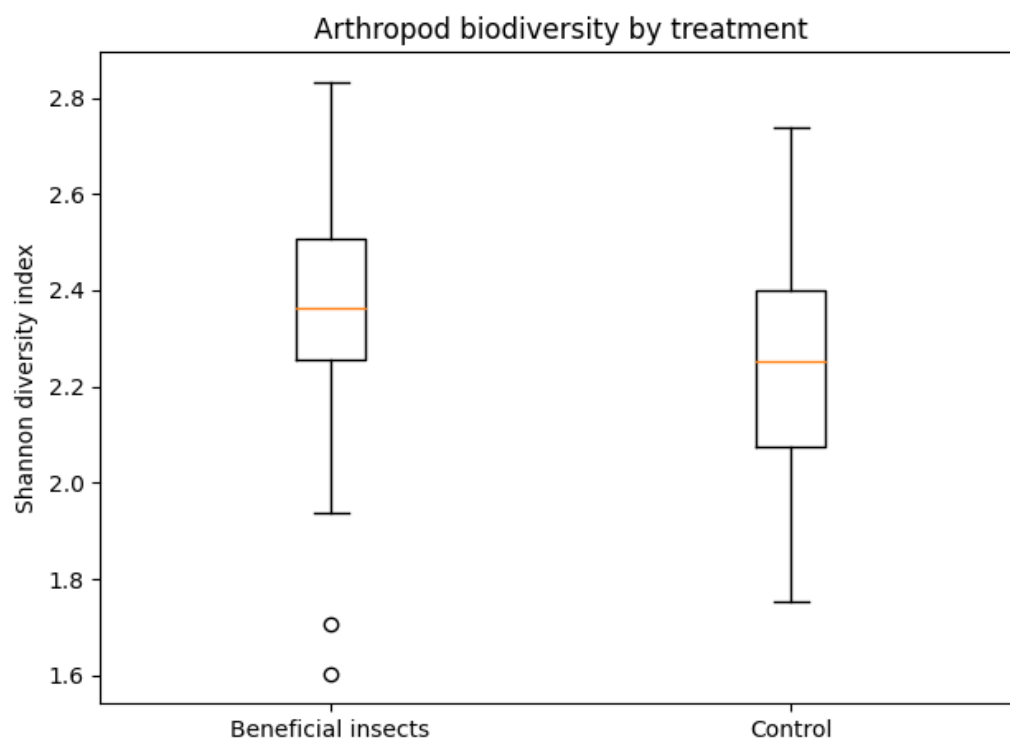


Figure 4: Boxplot of arthropod Shannon diversity index in intervention versus control blocks.

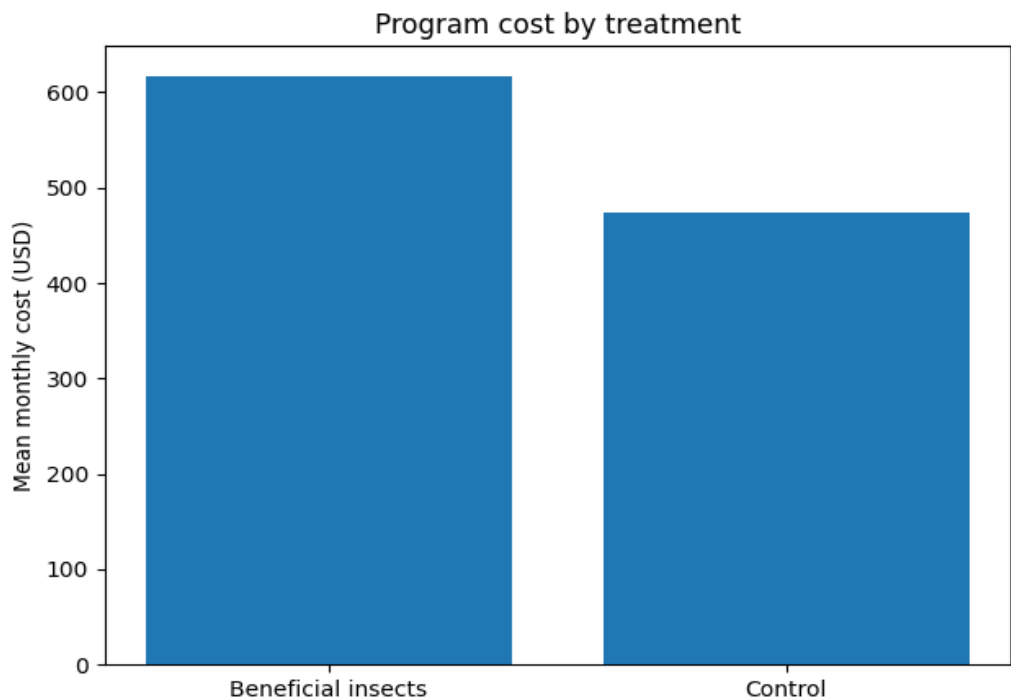


Figure 5: Mean monthly program costs by treatment group.

3.4 Beneficial Insect Establishment

Counts of beneficial insects were consistently higher in the intervention blocks (Table 4). Lady beetles averaged 4.0 per sweep sample in the beneficial insect arm compared with 2.8 in controls. Similarly, lacewing counts were 3.2 versus 2.2, and parasitoid mummies were 2.3 versus 1.5. These findings confirm that released natural enemies established successfully and contributed to pest suppression.

Table 4: Mean Beneficial Insect Counts by Treatment Group

Beneficial insect	Beneficial Insects	Control
Lady beetles (per sweep)	4.0	2.8
Lacewings (per sweep)	3.2	2.2
Parasitoid mummies	2.3	1.5

3.5 Summary of Findings

Overall, integrating beneficial insects into urban pest management in Lahore significantly reduced pest abundance, plant damage, pesticide applications, and resident complaints, while enhancing biodiversity. Although program costs were moderately higher, the ecological and social benefits strongly support biological control as a sustainable alternative to conventional urban pest management.

4. Discussion

The current investigation demonstrates that the inclusion of beneficials effectively enhances urban pest control in Lahore, Pakistan, leading to significantly reduced pest and plant damage, fewer pesticide applications, and fewer resident complaints related to pest management, alongside increased biodiversity in urban areas. Such outcomes agree with those observed in larger-scale integrated pest

management (IPM) packages in Asia and Africa, wherein biological control is beneficial in reducing reliance on synthetic inputs and promoting ecosystem services (Pretty & Pervez Bharucha, 2015). Importantly, the level of pest suppression that we detected (~34% reduction) is relevant to the higher range of magnitudes observed in field trials, demonstrating that natural enemies can regulate urban pests in field trials (Feldmann & Vogler, 2021). Our results further support the hypothesis that the structural aspects of the urban landscape (vegetation cover and canopy density) affect pest dynamics and natural enemy persistence, as it has been shown that local habitat quality can modulate biological control strength (Arnold et al., 2019).

In addition to pest mitigation, the ecological and social values observed in this study are also critical for urban sustainability. The financial savings in the intervention arm associated with the reduced number of spray events are consistent with the growing evidence stressing the necessity of minimizing synthetic pesticide applications in urban areas because of concerns regarding resistance evolution and adverse non-target effects (Akhter et al., 2023; Zhu et al., 2016). The results indicate that threshold-based interventions, aided by the release of beneficial insects, can relax the chemical inputs of routine municipal spraying (where this remains the norm, as in Lahore) and yet not prejudice the desired pest control outcomes. In Pakistan, biological control initiatives against invasive plants and agricultural pests have been successful (Murtaza et al., 2022).

Another important discovery is an increase in arthropod biodiversity in blocks where insects are beneficial to crops. The increased Shannon index in the intervention blocks indicates both direct establishment of released natural enemies and lower collateral damage from pesticides. This result reflects global evidence that biocontrol can re-establish ecosystem functioning and stabilize arthropod communities (Wyckhuys et al., 2024). Habitat diversification (banker plants and flowering strips) is now better understood as vital for the support of all beneficial insects (Gossen & McDonald, 2020). Our findings provide strong evidence for integrating such practices into urban planning to enhance ecological resilience. However, the significant addition of

biodiversity to urban environments may also be transferable to ecosystem services that residents value, such as pollination and natural pest regulation, and thus, the nexus of ecological gain with greater quality of life (Parry, 2022).

This translates into a slightly elevated cost for the intervention arm from an economic standpoint, mainly because of the purchase and subsequent release of beneficial insects. Nonetheless, this was mitigated to some extent by reduced pesticide use and pesticide applicator labor, consistent with cost-effectiveness analyses in developing-country contexts (Akhter et al., 2023; Parry, 2022). These modest incremental costs are justified when balanced against long-term environmental returns and the reduced risks to public health from the spraying of chemicals. Additionally, fewer complaints from residents indicated community acceptance, highlighting the social benefits of adopting environmentally friendly pest management methods. Overall, these findings suggest the incorporation of biological control into the existing municipal IPM programs in Pakistan. Adapting to worldwide sustainable pest management practice will decrease the dependence of local authorities on pesticides, promote biodiversity, and bring about lower-cost and socially acceptable options (Pretty & Pervez Bharucha, 2015).

5. Conclusion

Despite their proven effectiveness in the urban ecosystem of Lahore, Pakistan, this study provides further evidence that the integration of beneficial insects as a component in urban pest management programs provides a sustainable and effective alternative to conventional pesticide-based approaches. These findings unequivocally indicate that blocks with natural enemy releases had significantly reduced pest levels, less damage to plants, fewer pesticide applications, and greater arthropod diversity than control blocks managed only with routine chemical sprays. Program costs were modestly greater due to the buy-release of beneficial insects, which, however, were partly compensated for through reduced insecticide and labor costs, and notably through the additional ecological and social benefits it provided. With significant improvements in biodiversity, reduced complaints by residents regarding pests indicate that

biological control options not only provide agronomic and environmental advantages but also improve urban livability and social acceptance of pest control programs. These findings resonate with the global literature on the value of incorporating biological control into IPM frameworks and highlight the need for chemical applications to be conducted based on a threshold, and not via calendar-based spraying. The current study provides a scalable model for Pakistan, where municipal pest management is still heavily dependent on synthetic insecticides, to shift towards more ecologically sustainable practices. Further research should investigate the long-term persistence of beneficial insect populations, interactions with urban habitat features, and potential interactions with other earth-friendly strategies such as botanical biopesticides and habitat diversification. In conclusion, the incorporation of biological control in urban systems plays an important role in lowering reliance on chemicals, conserving biodiversity, and achieving sustainable urban ecosystem management in developing country contexts.

REFERENCES

- Abbas, M., Abbas, S., Faraz, I., Hussain, N., Aslam, M., Irshad, M., Khaliq, M., Ghaffar, A., Parveen, Z., & Nadeem, M. (2023). Comparing traditional and contemporary approaches to integrated pest management in major field crops. *Pakistan Journal of Agricultural Research*, 36(3), 183-192.
- Akhter, W., Shah, F. M., Yang, M., Freed, S., Razaq, M., Mkindi, A. G., Akram, H., Ali, A., Mahmood, K., & Hanif, M. (2023). Botanical biopesticides have an influence on tomato quality through pest control and are cost-effective for farmers in developing countries. *Plos one*, 18(11), e0294775.
- Arnold, J. E., Egerer, M., & Daane, K. M. (2019). Local and landscape effects to biological controls in urban agriculture—a review. *Insects*, 10(7), 215.
- Brenner, B. L., Markowitz, S., Rivera, M., Romero, H., Weeks, M., Sanchez, E., Deych, E., Garg, A., Godbold, J., & Wolff, M. S. (2003). Integrated pest management in an urban community: a successful partnership for prevention. *Environmental Health Perspectives*, 111(13), 1649-1653.
- Bryant, T., & Reay-Jones, F. (2020). Integrated pest management: Concepts and strategies.
- Chohan, S. M., Sohail, M. S., & Sharif, I. (2024). SUSTAINABLE PEST MANAGEMENT STRATEGIES FOR COTTON CROP IN PAKISTAN: A REVIEW. *Journal of Agricultural Research (JAR)*. 62(3), 181-192.
- Fahad, S., Saud, S., Akhter, A., Bajwa, A. A., Hassan, S., Battaglia, M., Adnan, M., Wahid, F., Datta, R., & Babur, E. (2021). Bio-based integrated pest management in rice: An agro-ecosystems friendly approach for agricultural sustainability. *Journal of the Saudi Society of Agricultural Sciences*, 20(2), 94-102.
- Feldmann, F., & Vogler, U. (2021). Towards sustainable performance of urban horticulture: ten challenging fields of action for modern integrated pest management in cities. *Journal of Plant Diseases and Protection*, 128(1), 55-66.
- Gossen, B. D., & McDonald, M. R. (2020). New technologies could enhance natural biological control and disease management and reduce reliance on synthetic pesticides. *Canadian Journal of Plant Pathology*, 42(1), 30-40.
- Murtaza, G., Naeem, M., Manzoor, S., Khan, H. A., Eed, E. M., Majeed, W., Makki, H. A., Ramzan, U., & Ummara, U. E. (2022). Biological control potential of entomopathogenic fungal strains against peach Fruit fly, *Bactrocera zonata* (Saunders)(Diptera: Tephritidae). *PeerJ*, 10, e13316.

- Parry, H. (2022). Economic benefits of conservation biocontrol: A spatially explicit bioeconomic model for insect pest management in agricultural landscapes. *Frontiers in Ecology and Evolution*, 10, 970624.
- Pecenka, J. R., Ingwell, L. L., Foster, R. E., Krupke, C. H., & Kaplan, I. (2021). IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation. *Proceedings of the National Academy of Sciences*, 118(44), e2108429118.
- Pretty, J., & Pervez Bharucha, Z. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects*, 6(1), 152-182.
- Wyckhuys, K. A., Gu, B., Fekih, I. B., Finger, R., Kenis, M., Lu, Y., Subramanian, S., Tang, F. H., Weber, D. C., & Zhang, W. (2024). Restoring functional integrity of the global production ecosystem through biological control. *Journal of environmental management*, 370, 122446.
- Zhu, F., Lavine, L., O'Neal, S., Lavine, M., Foss, C., & Walsh, D. (2016). Insecticide resistance and management strategies in urban ecosystems. *Insects*, 7(1), 2.

