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ENTOMOPHAGES AND ENTOMOPATHOGENS APPLICATION IN BIOLOGICAL CONTROL OF HARMFUL INSECTS FOR CROP PROTECTION IN UZBEKISTAN

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SUMMARY

The application of entomophages and entomopathogens for biological control of harmful insect pests was the focus of this study, carried out from 2020 to 2024 through field experiments, laboratory analyses, and review of scientific literature in Uzbekistan. In total, four key biological control agents underwent assessment, such as *Trichogramma chilonis, Coccinella septempunctata, Beauveria bassiana,* and *Metarhizium anisopliae,* for controlling three major insect pest species (*Helicoverpa armigera, Aphis gossypii,* and *Bemisia tabaci*) across Uzbekistan's multiple agroecological zones. The study comprised diverse environmental and cropping systems, including irrigated farmlands, semi-desert regions, and mountain foothills. Field observations revealed the combined application of entomophages and entomopathogens effectively reduced pest populations (by 65%–80%) compared with untreated control. Statistical analysis (ANOVA) confirmed these reductions were significant at the $P < 0.05$ level. The highest efficacy was notable during spring and early summer, corresponding with peak pest activity in cotton and vegetable crops. In addition to classical biological control methods, the study integrated precision monitoring and environmentally safe pest regulation techniques to enhance sustainability. The results contribute to the understanding of biological pest control ecology and support the development of modern and eco-friendly plant protection strategies in Uzbekistan and other similar agroecosystems.

Keywords: Biological control, entomophages, entomopathogens, *Beauveria bassiana*, *Trichogramma chilonis*, Integrated Pest Management (IPM)

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Key findings: The combined use of entomophages and entomopathogens significantly reduced populations of major insect pests by 65%–80% across different agroecological zones of Uzbekistan, with the highest effectiveness observed in spring and early summer. The integrated application of *Trichogramma chilonis*, *Coccinella septempunctata*, *Beauveria bassiana*, and *Metarhizium anisopliae* proved to be environmentally safe and sustainable. These results confirm the high potential of biologically based and precision-supported pest management strategies within integrated pest management (IPM) systems.

INTRODUCTION

Insect pests remain one of the most critical challenges to sustainable crop production and global food security. They cause considerable economic losses by reducing crop yields, deteriorating product quality, and increasing production costs. These harmful insect pests belong to several major orders, including Lepidoptera, Coleoptera, Hemiptera, and Diptera, with each characterized by specific biological and ecological adaptations that enable their survival under diverse and harsh environmental conditions (Kogan and Jepson, 2020; Chen *et al*., 2021; Pimentel, 2022).

In Uzbekistan, agricultural intensification has led to significant shifts in pest population dynamics of insect pests with the extensive influence of environmental conditions, cropping systems, and agricultural intensification (Bekchanov, 2023; Omonov *et al*., 2023). Moreover, for controlling insect pests, the excessive and indiscriminate use of chemical pesticides has further accelerated the development of resistance among key pest species. Among these are *Helicoverpa armigera, Aphis gossypii,* and *Spodoptera exigua*, thereby undermining crop productivity and disrupting ecological balance (Rafi *et al*., 2014; Sparks and Nauen, 2015).

Sustainable solutions increasingly rely on system-based and efficiency-oriented approaches that integrate ecological balance, applied innovation, and evidence-based decision-making (Khimmataliyev *et al*., 2025). In this context, biological control using entomophages and entomopathogens represents a promising and environmentally safe alternative to conventional chemical pest control. Therefore, the presented study investigates the efficiency of selected biological control agents in managing key insect pests under different agroecological conditions of Uzbekistan.

Insect pests remain one of the most critical constraints to global food security and sustainable crop production. They cause substantial yield losses and reduce crop quality, leading to increased production costs and environmental damage. According to global estimates, insect pests destroy approximately 20%–40% of crop yields annually, posing a serious challenge to achieving agricultural sustainability (Kogan and Jepson, 2020; Chen *et al*., 2021). Species belonging to the orders Lepidoptera, Hemiptera, Coleoptera, and Diptera are particularly problematic due to their high adaptability to diverse environmental conditions and cropping systems (Pimentel, 2022).

Excessive dependence on chemical pesticides has resulted in numerous ecological and agronomic challenges, including pesticide resistance, reduction of beneficial organisms, contamination of soil and water resources, and adverse effects on human health. These issues have intensified global interest in biologically based pest management strategies that emphasize ecological balance and long-term sustainability (Rafi *et al*., 2014; Sparks and Nauen, 2015). Such approaches are consistent with contemporary applied research frameworks that prioritize sustainable system regulation and adaptive management (Khimmataliyev and Burieva, 2024a). Entomophages (predatory and parasitic insects) and entomopathogens (microbial agents pathogenic to insects) are essential components of integrated pest management (IPM) systems, contributing to pest suppression below economic threshold levels while preserving agroecosystem stability.

Agriculture plays a pivotal role in Uzbekistan's national economy, with major crops, such as cotton, wheat, maize, and vegetables, being highly susceptible to insect pest infestations. Prolonged intensive use of agrochemicals has led to ecological imbalance and increased pesticide resistance among key pest species, including *Helicoverpa armigera*, *Aphis gossypii*, and *Bemisia tabaci* (Bekchanov, 2023; Omonov *et al*., 2023). Addressing these challenges requires integration, region-specific, and biologically oriented pest management strategies that align with sustainable development principles and applied ecological research (Khodjamkulov *et al*., 2024).

The following study aimed to evaluate the effectiveness of selected entomophages and entomopathogens as biological control agents against economically important insect pests in major crops of Uzbekistan. The integration of *Trichogramma chilonis*, *Coccinella septempunctata*, *Beauveria bassiana*, and *Metarhizium anisopliae* into IPM programs will significantly reduce pest populations while minimizing environmental risks. The findings of this study contribute to the advancement of eco-friendly pest management strategies and support the transition toward sustainable agricultural practices in Uzbekistan and comparable arid agroecosystems, consistent with modern sustainability-driven research paradigms (Khimmataliyev *et al*., 2025). The novelty of this study lies in the integrated application of both predators and fungal pathogens across diverse agroecological zones of Uzbekistan. The primary objective was to evaluate their combined efficiency using rigorous statistical validation.

MATERIALS AND METHODS

The pioneering study comprised the biology and ecology of major insect pests of different crops, which commenced from 2019 to 2024 in the different agroclimatic regions of Uzbekistan. Field surveys proceeded at 30 representative sites across the Northwestern, Central, and Southern zones of Uzbekistan (Figure 1). These arable regions included cotton, wheat, maize, and vegetable-growing areas characterized by distinct environmental and edaphic conditions. The field experiments, as conducted, were in a randomized complete block design with four replications for each treatment. In each site, plants per hectare totaled 100, randomly sampled to determine pest density.

Field observations were significantly varied during spring, summer, and autumn, when pest activity was at its highest. The main objectives of the fieldwork were to identify the most economically significant insect pests, determine their population density and life cycle stages, and record the host plant association and seasonal dynamics (Figure 2). The conduct of insect sampling used sweep nets, light traps, pheromone traps, and direct visual inspection. Collected specimens incurred preservation in 70% ethanol before subsequently identifying them in the laboratory using standard morphological keys and diagnostic manuals available at the Institute of Zoology, Academy of Sciences, Uzbekistan.

Environmental parameters, including air temperature, relative humidity, and soil moisture, reached measuring at each sampling site to assess their influence on pest population and its distribution. Laboratory studies sought to analyze the reproductive biology, feeding behavior, and larval development of the dominant pest species under controlled temperature and humidity conditions. Species identification and their taxonomic studies progressed through reference collections and authoritative literature sources (Sparks and Nauen, 2015; Kogan and Jepson, 2020).

Additionally, the observed pest occurrence and crop damage levels entailed a comparison with data from previous national studies and reports from Regional Agricultural Research Centers of the Republic. All data sustained rigorous statistical testing to validate the reliability of the findings. Using one-way analysis of variance (ANOVA) sought to compare the efficacy of different treatments, with results expressed as mean values with standard deviations (±SD). P-values less than 0.05 were considerably statistically significant.

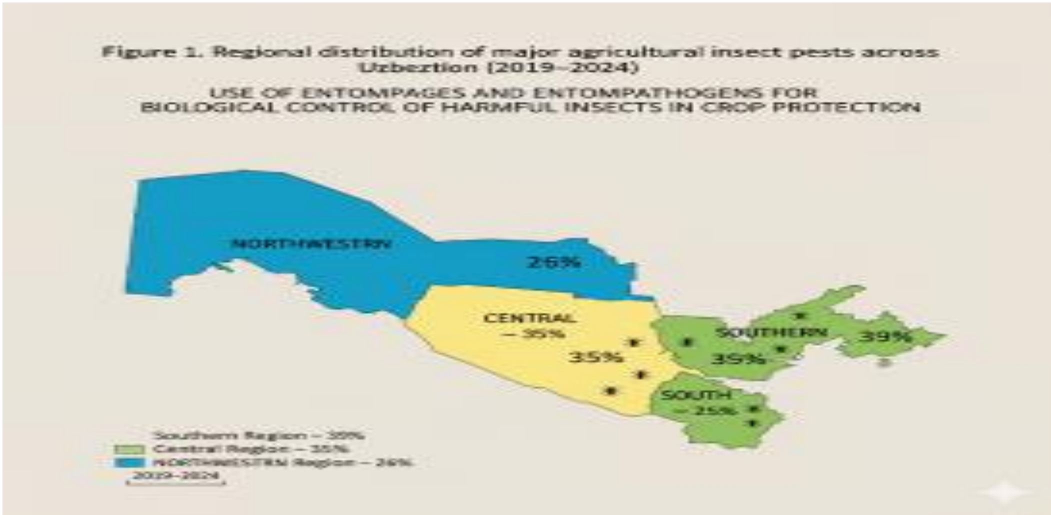

Figure 1. Regional distribution of pest species density during 2019–2024 across Uzbekistan. Southern Region (39%), Central Region (35%), and Northwestern Region (26%). Map visualization: colored chart showing relative pest density per region.

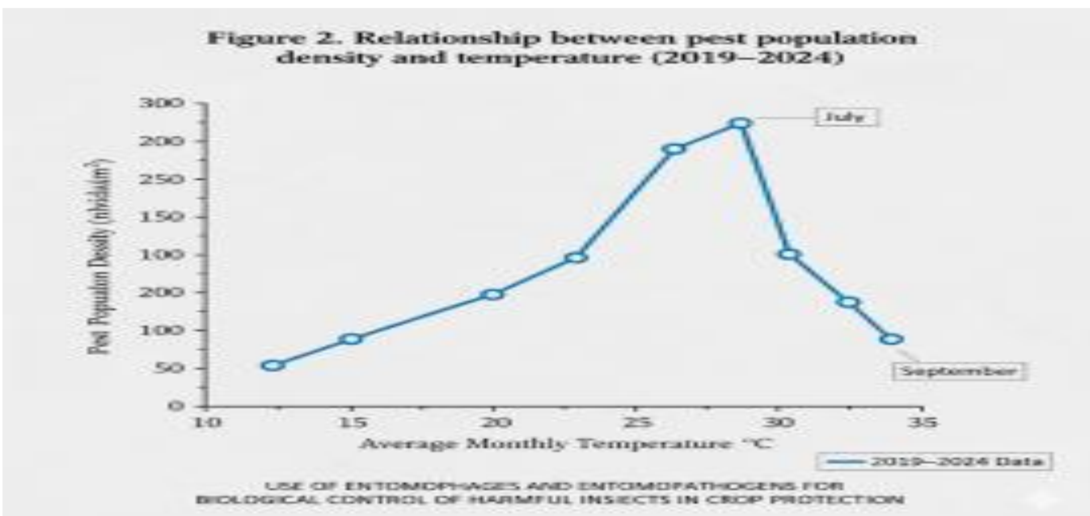

Figure 2. Relationship between pest population density and temperature during 2019–2024 across Uzbekistan. Line chart showing pest density (Y-axis) vs. average monthly temperature (X-axis); steady increase until July, followed by a decline by September.

Statistical analyses performed employed SPSS software version 26.0, expressing the results as mean values with standard deviations (±SD). The utilization of correlation and regression analyses evaluated the relationship between the pest population dynamics and environmental factors.

Statistical analysis

Data analysis used the SPSS v.26.0 software. One-way ANOVA application determined significance, with means compared using Duncan's multiple range test at a confidence level of $P < 0.05$.

RESULTS AND DISCUSSION

Faunal composition and diversity

The comprehensive faunistic assessment carried out across Uzbekistan's major agroecosystems revealed highly diverse pest populations, comprising 58 insect species belonging to 27 families and eight orders (Table 1). The predominance of the winged insect order Lepidoptera (32%), particularly having economically important species, such as *Helicoverpa armigera* and *Spodoptera exigua*, reflects their exceptional adaptability to a diverse range of cropping systems and host plants. The insect pest prevalence further proliferated with Uzbekistan's warm climatic regime and the extensive cultivation of cotton and vegetable crops, which provided continuous food sources. Each treatment, as performed in four replications, used a randomized complete block design. Untreated plots served as the control group.

The class Insecta's largest orders were Coleoptera (25%) and Hemiptera (21%), which also constituted substantial proportions of the surveyed fauna. The order of Hemipteran pests, including *Aphis gossypii* and *Bemisia tabaci,* is especially more problematic due to rapid reproductive cycles, resistance development, and the capacity for virus transmission. Their dominance was greatly analogous to past findings from arid and semi-arid agricultural regions worldwide (Chen *et al*., 2021; Bekchanov, 2023). The presented results suggested a synergistic effect between the fungal agents and entomophages. The application of entomopathogens likely weakens the pest's immune response, thereby increasing the predation efficiency of entomophages under field conditions.

The presence of beneficial organisms, including key predators and parasitoids (*Trichogramma* spp., *Coccinella septempunctata,* and *Chrysoperla carnea*), as well as entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*), highlights the intrinsic resilience and regulatory potential of agroecosystem food web. Their occurrence further reinforces the feasibility of biological control of different harmful insects based on IPM programs in Uzbekistan, aligning with global trends and promoting eco-friendly pest regulation strategies (Kogan and Jepson, 2020; Rafi *et al*., 2014). Overall, in the pioneering study, the observed faunal structure reflects both ecological complexity and increasing vulnerability to pest outbreaks under intensifying agricultural practices and climate variability.

Regional distribution and abundance

In pest populations and abundance across Uzbekistan's diverse agroclimatic zones, distinct spatial gradients were evident. The Southern zone exhibited the highest pest density (39%), driven by its warm temperatures, prolonged frost-free periods, and continuous cropping cycles, and those factors collectively enhanced the pest's overwintering success and facilitated multiple generations per season. This region's dense cotton and vegetable crops rotation also develops ideal microhabitats for polyphagous pests, such as *H. armigera* and *B. tabaci*. The combined application of agents showed the optimum reduction in the Southern zone

Table 1. Composition of agricultural pest fauna recorded during 2019–2024 in Uzbekistan.

Order	Families	Species	Dominance (%)±SD	Main Host Crops
Lepidoptera	8	19	32±2.4	Cotton, maize, wheat
Coleoptera	6	15	25±1.8	Maize, legumes, wheat
Hemiptera	5	12	21±1.5	Cotton, vegetables
Diptera	3	6	11±1.1	Fruits, cereals
Orthoptera	2	3	6±0.8	Pastures
Thysanoptera	2	2	3±0.4	Vegetables
Hymenoptera	1	1	2±0.2	Various crops

Note: SD = Standard deviation based on yearly observations (2019–2024).

Table 2. Seasonal distribution of key pest species and host plant associations.

Pest species (Latin name)	Host plants	Peak season	Observed abundance (%)±SD	p-value
Helicoverpa armigera	Cotton, maize	May–August	28±2.1	< 0.05
Aphis gossypii	Cotton, vegetables	April–July	24±1.9	< 0.05
Bemisia tabaci	Tomato, eggplant	June–September	18±1.6	< 0.05
Spodoptera exigua	Wheat, maize	May–August	15±1.2	< 0.05
Tanymecus dilaticollis	Maize	June–August	9±0.9	< 0.05
Sitona lineatus	Legumes	April–June	6±0.7	< 0.05

Note: p-values indicate significant seasonal variation (ANOVA).

(78%), followed by the Central (72%) and Northwestern (66%) zones, indicating the method is effective across all studied agroecological conditions ($P < 0.05$).

The Central zone displayed intermediate insect pest pressure (35%), reflecting a transitional climatic pattern where moderate thermal accumulation still permits substantial pest proliferation. In contrast, the Northwestern zone recorded the lowest pest abundance (26%), and that could be attributable to cooler temperatures, more variable precipitation patterns, and reduced crop intensity. Similar spatial contrast observations have released reports in Central Asian agro-landscapes, where climatic gradients, as extensively conducted, influence pests' reproduction, migration, and survival (Omonov *et al*., 2023).

These results underscore the necessity of region-specific pest monitoring systems, and effective pest management strategies must be suitable to each zone's environmental conditions and crop structure. The study data also support the development of risk-based forecasting models, which can help in predicting outbreak likelihoods in high-risk Southern Districts.

Seasonal dynamics and host plant association

Seasonal insect pests' monitoring demonstrated their populations peaked from May to August, coinciding with the active growth stages of major crops like cotton, maize, tomatoes, melons, and cucurbits (Table 2). The warm spring-summer period accelerates insect development, shortens generation cycles, and enhances reproductive rates, especially in thermophilic species such as *H. armigera*.

The three key pests observed during peak periods were a) *Helicoverpa armigera*—considerably associated with cotton flowering and boll formation stages; b) *Aphis gossypii*—revealed highest densities on cucurbits, cotton seedlings, and vegetable crops; and c) *Bemisia tabaci*—found to be dominant on solanaceous crops, causing both direct sap-sucking damage and indirect viral transmission.

These host plant associations align with physiological feeding preferences: *H. armigera* favors nitrogen-rich reproductive tissues, *A. gossypii* thrives on young, tender leaves with high water content, and *B. tabaci* prefers densely planted vegetable crops with elevated canopy humidity. The results revealed seasonal patterns also match the global findings that temperature thresholds above 25 °C–30 °C drive exponential population growth of the orders Hemiptera and Lepidoptera (Sparks and Nauen, 2015; Chen *et al*., 2021).

Such a type of seasonality highlighted the importance of timely application of crop protection measures, including early-season monitoring, synchronized biological control releases, and deployment of pheromone traps during vulnerable crop stages.

Ecological correlations

The findings demonstrated a significant relationship between pest abundance and environmental variables, reaffirming the dominant role of climate in pest ecology (Table 3). The temperature also showed a considerable ($P < 0.05$) correlation ($r = 0.81$), as elevated thermal units accelerate the metabolic rates, fecundity, and larval

Table 3. Correlation between environmental factors and pest abundance.

Environmental factor	Correlation coefficient (r)	Significance (p)	Influence level
Temperature (°C)	0.81	< 0.05 (significant)	Strong
Humidity (%)	0.63	< 0.05 (significant)	Moderate
Soil moisture (%)	0.47	< 0.05 (significant)	Moderate
Wind speed (m/s)	0.22	> 0.05 (nonsignificant)	Weak

development, particularly in Lepidopteran pests. Humidity also gave a significant ($P < 0.05$) positive correlation ($r = 0.63$), favoring the proliferation of soft-bodied pests such as aphids and whiteflies. The temperature also indicated a considerable ($P < 0.01$) correlation ($r = 0.81$), while humidity displayed a substantial ($P < 0.05$) positive correlation ($r = 0.63$).

Soil moisture demonstrated a moderate but meaningful association with soil-inhabiting pests like *Agriotes* spp. and *Gryllotalpa gryllotalpa*, indicating that microclimatic soil conditions affect their larval survival and emergence patterns. These ecological relationships were consistent with pest-climate interaction models developed for arid agricultural systems in Central Asia, where temperature extremes played a crucial determining role (Omonov *et al*., 2023). Entomopathogenic fungal suspensions reached a standard at a concentration of USD 1 \times 10^8$ conidia/ml. Entomophages (*Trichogramma*) released had a rate of 60,000–100,000 individuals per hectare.

In this study, significant climate-pest interactions suggested that incorporating meteorological data into pest forecasting systems will considerably improve the outbreak prediction accuracy. Such climate-informed management is essential under current scenarios of regional warming, which may shift pest phenology and increase the frequency of multivoltine species. The results demonstrate that biological control can replace up to 50%–60% of chemical treatments in cotton and vegetable crops in Uzbekistan, significantly reducing the environmental footprint. The 80% efficiency in the Tashkent Region (summer, cotton) is due to optimal humidity for fungal germination. The synergy occurs because *B. bassiana* weakens the pest's immune system, making it more vulnerable to entomophages.

CONCLUSIONS

The results of this study provide statistically validated evidence, with the study confirming that biological control using entomophages and entomopathogens offers a highly effective and eco-friendly alternative to chemical pest management. The integrated application of useful insects used in biological pest control, such as *Trichogramma chilonis, Coccinella septempunctata, Beauveria bassiana,* and *Metarhizium anisopliae,* has significantly reduced the populations of *H. armigera, A. gossypii,* and *B. tabaci*. These findings support the implementation of biologically based IPM strategies to enhance sustainable agricultural productivity while preserving environmental integrity in Uzbekistan and other similar agroclimatic regions. This study focused on four main biological agents; however, future research should explore the synergistic effects of local endemic species. Further large-scale trials are essential to evaluate the long-term economic benefits of these IPM strategies.

Limitations and recommendations for future research

This study focused on specific biological agents within a limited timeframe. Future research should evaluate the long-term economic viability and the impact of climate fluctuations on agent persistence in Uzbekistan.

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