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Innovative Pest Control Methods Using Entomophages in Southeastern Kazakhstan

Nurzhan Mukhamadiyev[1], Bakhytzhan Duisembekov[2], Sholpan Bastaubaeva[3], Aizhan Chadinova[4], Gulnaz Mengdibayeva[5]*, Aigerim Koigeldina[6], Nurbakyt Kurmangaliyeva[5], Gaziza Sarsenbayeva[2]

[1]Department of Biological Plant Protection, Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan.
[2]Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan.
[3]Kazakh Research Institute of Agriculture and Plant growing, Almaty, Kazakhstan.
[4]Knowledge Dissemination Center, Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan.
[5]Laboratory for the Protection of Forests and Green Spaces, Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan.
[6]Phytopathology Laboratory, Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan.

ABSTRACT

This study aimed to develop a system of biological protection methods for managing pests and diseases in order to support organic crop production under the conditions of southeastern Kazakhstan. Field experiments were conducted during the 2024 growing season across multiple crops, including wheat, barley, maize, and rapeseed. The study involved systematic pest monitoring, evaluation of microbial biopesticides, and deployment of natural enemies (Trichogramma spp., Bracon hebetor, Chrysoperla carnea). Applications were carried out using unmanned aerial vehicles (UAVs), and pest population dynamics were assessed at regular intervals to determine the efficacy of the treatments. Across all crops, 8 to 16 pest species were identified depending on the crop type. Biopesticide combinations demonstrated high effectiveness against key pests such as Plutella xylostella, Oulema melanopus, Eurygaster integriceps, Haplotrips tritici, and Schizaphis graminum, with control rates ranging from 84% to 100% after 7 days. The release of entomophages reduced populations of Helicoverpa armigera by up to 82.6% in later generations. Fungal and viral diseases were less prevalent but present on cereals and maize. The integrated use of microbial agents, beneficial insects, and UAV technology proved to be a sustainable and highly effective strategy for crop protection. These results provide a viable model for transitioning to environmentally safe pest control in organic farming systems across similar agroecological zones.

Keywords: *Biological crop protection, Entomophages, Microbial biopesticides, UAV application, Phytosanitary monitoring, Organic agriculture*

Corresponding author: Gulnaz Mengdibayeva
e-mail ✉ www.gulnaz87.kz@mail.ru
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INTRODUCTION

In the context of global climate change, increasing pest resistance to chemical agents, and rising environmental standards for agricultural products, crop protection is becoming an increasingly urgent issue (Uzakbayeva *et al.*, 2026). The global pest pressure has increased significantly due to climate change, globalization, and changes in land use (Kulibaba *et al.*, 2024). Spence *et al.* (2019) went further to highlight that the emerging global pest pressure, which has a significant effect on plant health, can also affect the mental and physical health of humans. In Central Asia, the issue of pest pressure cannot be overlooked. Zhou *et al.* (2022) reported that in China, global climate change has led to an increase in potato insect pests. Tegtmeier *et al.* (2024) also reported that an increase in pest and disease pressure has led to a decline in wild apple trees.

Kazakhstan, with its substantial agricultural capacity, faces similar challenges. Southeastern regions of the country are characterized by high pest pressure, diverse cropping patterns, and a clear need for sustainable and environmentally safe plant protection technologies. Although chemical crop protection has shown some effectiveness, there has been a notable increase in pest resistance and pesticide residues in the environment and food products. This issue is particularly evident in rapeseed cultivation, where outbreaks of insect pests, including the diamondback moth (*Plutella xylostella*), have intensified in recent years (Kholod & Korenyuk, 2016; Soroka *et al*., 2016; Churikova & Silaev, 2020; Shpanev, 2021; Adilkhankyzy *et al*., 2022; Mukhamadiyev *et al*., 2023). Pesticide use in agriculture in Kazakhstan continues to increase. Kenenbayev *et al*. (2024) reported that over the last decade, their utilization per unit area of agricultural land has nearly tripled. Pesticides used in farming leave hazardous residues in soil, water, and plants, posing a risk to human health and the environment. Organic agriculture relies on biological processes, such as manure, straw, and siderates, to maintain soil fertility and increase output. Mombayeva *et al*. (2025) also highlighted that for most pests, such as Psylliodes chrysocephalus L., which possess an increased reproduction rate and a growing resistance to conventional insecticides, biological pest control methods are advisable.

From a different perspective, Azhbenov *et al*. (2024) suggested that for migratory pests such as locusts, there is a need for precise application of pesticides to prevent contamination and waste. Azhbenov *et al*. (2024) proposed the use of a UAV for localized biopesticide application. They further concluded that by implementing UAV-based precision agriculture, it is possible to create thematic diagrams showing the dispersion of migratory locusts. This method of precision agriculture also allows for a safe and eco-friendly approach. Azhbenov *et al*. (2024) also reported that a specific biological agent, such as Actarophyte (2.0), exhibited high locust mortality rates when applied via UAVs.

While there is a considerable body of research dedicated to crop protection, most of it focuses on synthetic insecticides and fungicides. Biological approaches, including the use of entomophages and microbial formulations, remain underutilized—especially in the specific agroclimatic conditions of southeastern Kazakhstan (Berdgaleeva *et al*., 2025). Even though promising work has been carried out on rapeseed protection in regions with comparable climates, such as Belarus and northern Kazakhstan (Pilyuk, 2018; Popova & Petrova, 2019; Sertek *et al*., 2020; AsselAbdibay *et al*., 2024; Adilkhankyzy *et al*., 2025), effective adaptation to local phytosanitary risks and seasonal variability remains limited (Alpysbayeva *et al*., 2024).

Therefore, this study aimed to develop a pest control strategy for cereal and legume crops in southeastern Kazakhstan using biopreparations and entomophages, combined with unmanned aerial vehicle (UAV) applications.

MATERIALS AND METHODS

Study site and agroclimatic conditions

The research was conducted in 2024 at the experimental fields of the Kazakh Research Institute for Plant Protection and Quarantine (KazNIIZiKR) located in the Karasai district of the Almaty region, in the village of Zhalpaksai. Laboratory studies were carried out at the Zhiembayev branch of KazNIIZiKR.

To study the development of beneficial insects and evaluate the effectiveness of entomophages, a field cage was installed. Nectar-producing plants were sown around the cage to attract various entomophagous species. Predators such as lady beetles, hoverflies, parasitoid wasps, and other beneficial insects require supplementary food sources, especially during periods of low prey availability. Nectar and pollen support their survival, reproduction, and active predation on pests. The advantage of planting nectariferous species lies in increasing biodiversity, which contributes to reducing the need for chemical pest control interventions. The hydrothermal regime of 2023–2024 created conditions favorable not only for crop growth but also for pest proliferation. This necessitated continuous monitoring and the implementation of adaptive biological protection strategies.

Research methods

Pest monitoring at organic demonstration plots was performed weekly. Standard entomological and phytosanitary techniques were used to track the development of harmful species. Pheromone traps were employed to detect the flight onset and intensity of Helicoverpa armigera and the corn borer, at a density of two traps per hectare.

Sampling of larger pests—such as Eurygaster integriceps, Oulema melanopus, adult click beetles, cereal leaf beetles, and lepidopteran larvae and eggs—was performed on 0.25 m^2 plots. Small and jumping insects (e.g., flea beetles) were captured using a gauze-covered Petlyuk box with a 50×50 cm base, placed directly on the soil.

In row crops, pest density was assessed within rows measuring 25–100 cm, with recalculations made per square meter. Twenty samples of five plants each or ten samples of ten plants were taken diagonally across the fields.

Field assessments of small insects and mites used two indicators: the percentage of infested plants and an infestation severity score. Field assessments of small insects and mites were carried out using two indicators: the percentage of infested plants and an infestation severity score. A 3-point scale was applied, where 1 point indicated light infestation with few individuals affecting less than 25% of the leaf surface; 2 points represented moderate infestation characterized by one or two colonies affecting 26–50% of the leaf area; and 3 points corresponded to heavy infestation with more than two colonies affecting over 50% of the leaf surface. When necessary, microscopic counting was conducted in the laboratory under a binocular microscope.

For internal stem-boring pests, destructive sampling of plant parts (shoots, stems) was used to identify insects and damage symptoms. Typically, 10 samples of 0.25 m^2 were analyzed.

To account for pests that are exposed but difficult to count visually due to their high mobility or excessive density in dense vegetation, sweep netting was used. Each sample consisted of 10–20 continuous sweeps with the net.

In 2024, a separate field experiment was conducted to assess the biological efficacy of treatments against the cereal aphid Schizaphis graminum. During the stem elongation to heading stages of winter wheat, plants were artificially infested with aphids at a standardized rate of 5–7 individuals per ear. This approach ensured a consistent infestation level to objectively compare the efficacy of different biopesticides. Treatments were then applied according to the experimental design, and aphid populations were monitored on days 3, 7, and 14 after application.

Methodology for colonization of entomophages and biological control of corn earworm

To study the development of beneficial insects and evaluate the effectiveness of entomophages, a field cage was installed. Nectar-producing plants were sown around the cage to attract various entomophagous species. Predators such as lady beetles, hoverflies, parasitoid wasps, and other beneficial insects require supplementary food sources, especially during periods of low prey availability. Nectar and pollen support their survival, reproduction, and active predation on pests. The advantage of planting nectariferous species lies in increasing biodiversity, which contributes to reducing the need for chemical pest control interventions.

During the growing season, the organic field was actively colonized by biological control agents such as *Trichogramma*, *Bracon*, and *Chrysopidae*. These entomophages played a key role in pest management. Trichogramma acted as an egg parasitoid, significantly reducing pest populations. Braconidae proved effective in targeting pest larvae, while Chrysopidae actively preyed on aphids, mites, and other small insects. Thanks to this efficient biological control, mass pest outbreaks were prevented, which allowed for a reduction in chemical treatments.

Among the Lepidopteran pests in corn crops, aside from the armyworm moth, the cotton bollworm (*Helicoverpa armigera*) is considered the most widespread and damaging. The cotton bollworm infests corn during the flowering and ear formation stages, which complicates insecticide applications. Its larvae penetrate the ears, often feeding beneath the leaf sheaths that cover the ears, primarily in the middle stalk layer. This layer is difficult to treat effectively and promptly with ground-based sprayers due to restricted access. Moreover, older larvae develop increased resistance to insecticides. All these factors contribute to the near absence of insecticide applications on corn in the latter half of the growing season, despite the relatively high pest pressure from cotton bollworm. The only rational solution to this problem is the use of biological methods, specifically the release of specialized entomophages targeting bollworms.

To determine the timing of bollworm flight, pheromone traps were installed on June 3, 2024. The trigger for releasing Trichogramma was set at catching five cotton bollworm adults per day on the traps.

Biological agents were released against the second and third generations of cotton bollworm. The entomophages were bred at the Ontustik branch of KazNIIZiKR. The first Trichogramma release was conducted when the daily catch reached five moths per pheromone trap, at a rate of 80,000 individuals per hectare. Seven days later, Ghabrobracon was released on the same field at a rate of 1,000 individuals per hectare **(Table 7).** Trichogramma is a hymenopteran egg parasitoid of lepidopteran pests, while Ghabrobracon is a highly effective parasitoid of lepidopteran larvae.

During the 2024 growing season, systematic pest monitoring, including soil excavation and population assessments, was conducted on various crops. On wheat, barley, and oats, sixteen pest species were identified with varying degrees of damage. These included several wireworm species (*Agriotes sputator*, *A. obscurus*, *Selatosomus latus*), darkling beetles (*Blaps halophila*, *Opatrum sabulosum*), the striped flea beetle (*Phyllotreta vittula*), the red-breasted leaf beetle (*Oulema melanopus*), wheat thrips (*Haplothrips tritici*), the Mauritanian and sunn bugs (*Eurygaster maura*, *E. integriceps*), the cereal aphids (*Schizaphis graminum*, *Sitobion avenae*), and several fly and flea beetle species (*Chlorops pumilionis*, *Meromyza nigriventris*, *Chaetocnema aridula*, *C. hortensis*).

On alfalfa, sainfoin, and soybean, ten pest species were observed, including wireworms (*A. sputator*, *S. latus*), darkling beetles (*B. halophila*), weevils (*Sitona lineatus*, *S. crinitus*), the green leafhopper (*Cicadella viridis*), the soldier beetle (*Cantharis rustica*), the clover cutworm (*Discestra trifolii*), the Turkestan spider mite (*Tetranychus turkestanicus*), and the soybean pod borer (*Leguminivora glycinivorella*).

On maize, eight key pests were identified: wireworms (*A. sputator*, *A. obscurus*), *B. halophila*, *O. sabulosum*, the meadow moth (*Loxostege sticticalis*), the European corn borer (*Ostrinia nubilalis*), the maize beetle (*Pentodon idiota*), and the cotton bollworm (*Helicoverpa armigera*).

On pea, rapeseed, and flax, eight pest groups were recorded, including leaf beetles (Chrysomelidae), caterpillars (*Papilio machaon*, *Plutella xylostella*, *Pieris* spp.), the turnip sawfly (*Athalia rosae*), crucifer flea beetles (*Phyllotreta cruciferae*), crucifer bugs (*Eurydema* spp.), and various aphids (Aphidoidea).

In total, 15 beneficial insect species were also recorded during the monitoring period, belonging to 11 families across 3 orders. Among these were three rare entomophagous species listed in the Red Book of Kazakhstan and the Almaty region: the tree mantis (*Hierodula tenuidentata*), the short-winged assassin bug (*Coranus subapterus*), and the minute lady beetle (*Stethorus punctillum*).

One critical outbreak occurred in spring on rapeseed crops between emergence and the second true leaf stage. Populations of diamondback moth (*Plutella xylostella*) exceeded the economic threshold (3–4 larvae per plant versus the threshold of 2–3).

Application of biological formulations—Aktarofit 1.8, GreenGold, Phytosporin-M, Extrasol, and Biosok—via unmanned aerial vehicles (UAVs) on spring rapeseed plots resulted in 94.4–100% larval mortality within 14 days post-treatment **(Table 1)**.

RESULTS AND DISCUSSION

Table 1. Biological efficacy of preparations against the diamondback moth (*Plutella xylostella* Curt.), 2024

Treatment Variants	Repetition	Larvae/Plan				Mortality Rate, % on Day of Counting		
		Before Treatment	Days After Treatment					
			3	7	14	3	7	14
Aktarofit 1.8 (*Streptomyces avermitilis*), 0.9 L/ha + Phytosporin-M (*Bacillus subtilis 26 D*), 0.5 L/ha + Ekstrasol (*Bacillus subtilis Ch-13*), 1.5 L/ha	1	3,8	1,8	1,0	0,0			
	2	2,3	1,5	1,1	0,0			
	Avg.	3,0	1,5	1,0	0,0	59,4	74,3	100

Greengold (*Azadirachta indica*) + Phytosporin-M (*Bacillus subtilis 26 D*), 0.5 L/ha + Biosok (worm metabolites), 1 L/ha	1	3,6	1,7	1,1	0,0			
	2	3,3	1,6	1,2	0,2			
	Avg.	3,4	1,6	1,1	0,1	56,7	71,8	94,4
Control	1	3,5	3,8	3,9	4,0			
	2	3,3	3,6	3,9	3,8			
	Avg.	3,4	3,7	3,9	3,9	0	0	0

The use of unmanned aerial vehicles (UAVs) offers several advantages in the application of biocontrol agents. These include the ability to access remote or hard-to-reach plots, efficient treatment of areas as small as one hectare, and low-altitude spraying, which minimizes product drift and loss. UAVs ensure precise, deep canopy coverage—even at night—and enable targeted treatment of problem zones. Compared to manned aerial spraying, UAV applications are more economical due to lower product use and greater precision.

In early spring, during the tillering phase of winter wheat, a noticeable presence of red-breasted leaf beetles (*Oulema melanopus*) was recorded, reaching densities of up to 10–11 adults per square meter. The sunn pest (*Eurygaster integriceps*) was also detected at near-threshold levels (0.9 adults/m^2).

As demonstrated in **Table 2**, the combination of Aktarofit 1.8 (0.9 L/ha), Phytosporin-M (0.5 L/ha), and Extrasol (1.5 L/ha), applied twice via UAV, showed high biological efficacy (85.9%) against *O. melanopus*.

Table 2. Biological efficacy of biopreparations against the cereal leaf beetle (*Oulema melanopus* L.) on winter wheat crops, 2024

Treatment Variants	Repetition	Larvae/m^2				Mortality Rate, %		
		Before Treatment	Days After Treatment					
			1	3	7	1	3	7
Aktarofit 1.8 (*Streptomyces avermitilis*), 0.9 L/ha + Phytosporin-M (*Bacillus subtilis 26 D*), 0.5 L/ha + Ekstrasol (*Bacillus subtilis Ch-13*), 1.5 L/ha	1	11,4	5,1	3,3	1,0			
	2	11,7	5,1	3,2	1,2			
	Avg.	11,5	5,1	3,2	1,1	52,7	73,9	85,9
Greengold (*Azadirachta indica*), 0.3 L/ha + Phytosporin-M (*Bacillus subtilis 26 D*), 0.5 L/ha + Biosok (worm metabolites), 1 L/ha	1	11,2	6,3	3,2	1,1			
	2	10,3	4,4	3,5	1,3			
	Avg.	1,7	5,3	3,3	1,2	50,9	73,1	84,6
Control (Untreated)	1	10,3	11,4	12,6	13,3			
	2	10,4	10,2	12,0	12,4			
	Avg.	10,3	10,8	12,3	7,8	-	-	-

The sunn pest is particularly harmful to cereal crops in both the adult and larval stages. Overwintered adults damage all above-ground plant parts, especially stems and ears, by piercing tissue at the base of the upper internode or the spikelet. This disrupts the transport of water, sugars, and amino acids, negatively affecting plant development and grain quality. As shown in **Table 3**, a biopesticide combination of Bitoxibacillin (3.0 L/ha) and Biosok (1.0 L/ha), applied twice via UAV, resulted in 89.4% control efficacy against *E. integriceps*.

Table 3. Biological efficacy of biopreparations against the sunn pest (Eurygaster integriceps Put.) on winter wheat crops, 2024

Treatment Variants	Repetition	Individuals/m^2				Mortality Rate, %		
		Before Treatment	Days After Treatment					
			3	7	14	3	7	14
Aktarofit 1.8 (Streptomyces avermitilis), 0.9 L/ha + Ekstrasol (*Bacillus subtilis Ch-13*), 2.0 L/ha	1	0,8	0,4	0,2	0,1			
	2	0,6	0,5	0,1	0,1			
	Avg.	0,7	0,45	0,15	0,1	56,2	81,2	89,4
Bitoksibacillin (*Bacillus thuringiensis var. thuringiensis*), 3.0 L/ha + Biosok (worm metabolites), 1 L/ha	1	0,6	0,3	0,2	0,1			
	2	0,4	0,7	0,2	0,2			
	Avg.	0,5	0,5	0,2	0,15	37,5	75,0	84,2
Control	1	0,6	0,7	0,8	0,9			

	2	0,8	0,9	0,8	1,0			
	Avg.	0,7	0,8	0,8	0,95	0	0	0

The control schemes implemented against *Eurygaster integriceps* demonstrated high levels of biological efficacy, reaching 84.2–89.4% by the seventh day post-treatment. Despite a slight reduction in technical efficiency observed when applying tank mixtures—as opposed to single-product applications—our institutional research indicates that simultaneous use remains economically justified when application timings coincide.

During the booting to heading stages of winter wheat, field monitoring revealed visible infestations of wheat thrips and cereal aphids. Thrips densities averaged 8–9 adults per stem, exceeding the economic threshold of 8–10. Aphid infestation reached 5–7 individuals per spike, which also surpassed treatment thresholds.

Wheat thrips (*Haplotrips tritici Kurd.*) has emerged in recent years as a significant pest of winter wheat, particularly during stem elongation and heading. Both adults and larvae feed on leaf tissues, causing leaf rolling, reduced photosynthesis, and the development of empty or underdeveloped spikelets. The pest's impact is especially severe in dry years, when feeding activity disrupts grain formation and reduces kernel weight.

As shown in **Table 4**, effective control of *H. tritici* was achieved using combinations of Aktarofit 1.8, Extrasol, and Bitoxibacillin with Biosok. Following two UAV applications, efficacy reached 87.7–88.8% by day seven.

Table 4. Biological efficacy of biopreparations against wheat thrips (*Haplotrips tritici Kurd.*) in winter wheat crops, 2024

Treatment Variants	Repetition	Thrips density (imago/stem)				Mortality Rate, %		
		Before Treatment	Days After Treatment					
			1	3	7	1	3	7
Aktarofit 1.8 (Streptomyces avermitilis), 0.9 L/ha + Extrasol (Bacillus subtilis C-13), 2.0 L/ha	1	8,3	7,3	3,9	1,1			
	2	8,5	6,5	3,2	1,1			
	Avg.	8,4	6,9	3,55	1,1	20,6	60,3	88,7
Bitoxibacillin (Bacillus thuringiensis var. thuringiensis), 3.0 L/t + Biosok (earthworm metabolite), 1.0 L/ha	1	8,7	7,1	3,9	1,1			
	2	8,3	6,7	3,3	1,3			
	Avg.	8,5	6,9	3,6	1,2	20,6	59,7	87,7
Control	1	8,6	8,9	9,1	10,2			
	2	8,2	8,5	8,8	9,3			
	Avg.	8,4	8,7	8,95	9,75	0	0	0

The cereal aphid (*Schizaphis graminum*) is one of the most damaging sucking pests of cereal crops. Large infestations impact both spikes and leaves, causing deformation, delayed plant development, and substantial yield losses. When populations exceed 50 individuals per plant, losses may reach 10–14%.

In 2024, during the heading stage, an artificial infestation experiment was conducted on winter wheat using 5–7 aphids per spike to assess the effectiveness of biological treatments. As presented in **Table 5**, the applied biopreparations—Aktarofit 1.8, Phytosporin-M, Extrasol, and Bitoxibacillin with Biosok—demonstrated strong biological activity, reducing aphid populations by 91.9–92.5% by day seven post-treatment.

Table 5. Biological efficacy of biopreparations against greenbug aphid (*Schizaphis graminum*) in winter wheat, 2024

Treatment Variants	Repetition	Thrips density (imago/stem)				Mortality Rate, %		
		Before Treatment	Days After Treatment					
			1	3	7	1	3	7
Aktarofit 1.8 (Streptomyces avermitilis), 0.9 L/ha + Phytosporin-M (Bacillus subtilis 26D), 0.5 L/ha + Extrasol (Bacillus subtilis C-13), 1.5 L/ha	1	6,4	3,8	1,4	0,6			
	2	6,5	3,7	1,2	0,5			
	Avg.	6,45	3,75	1,3	0,55	42,2	81,5	92,5
Bitoxibacillin (Bacillus thuringiensis), 3.0 L/t + Phytosporin-M 0.5 L/ha + Biosok 1.0 L/ha	1	6,8	3,9	1,2	0,7			
	2	6,3	3,6	1,3	0,5			

	Avg.	6,5	3,75	1,25	0,6	42,5	82,2	91,9
Control	1	6,9	7,0	7,2	7,3			
	2	6,6	6,7	6,9	7,5			
	Avg.	6,75	6,85	7,05	7,4	0	0	0

In July, the cotton bollworm (*Helicoverpa armigera*) was identified as a key pest on maize crops, with observed densities of up to 7–8 larvae per 100 plants. While this did not exceed the economic threshold level of 10–20 larvae per 100 plants, early detection was critical for timely management.

Egg-laying was predominantly observed on the upper surface of maize leaves, though eggs were also found on the undersides of leaves, husks, silks, and tassels. Initial larval emergence was recorded between July 10 and 15, with peak hatching typically occurring from July 13 to 18. The interval between oviposition and larval emergence varied from 7 to 14 days across years and appeared to be primarily influenced by the accumulation of mean daily temperatures. No clear correlation was established between precipitation levels and hatching duration, although the longest development period (14 days) coincided with the lowest recorded rainfall (4 mm). The flight period of adult moths was prolonged, with oviposition and larval emergence phases overlapping significantly. As a result, larvae of different instars could be found simultaneously on the same plant. For chemical control to be effective, it is essential to target early instar larvae before they burrow into plant tissues and develop resistance to insecticides. Delays in treatment—even by 2 to 3 days—can substantially reduce pesticide efficacy.

To ensure optimal control, a two-spray program was recommended, with the second application carried out no later than 10 days after the first. The efficacy of various biological and botanical insecticides applied against *H. armigera* on maize is presented in **Table 6**.

Table 6. Biological efficacy of biopreparations and entomophages against cotton bollworm (*Helicoverpa armigera Hb.*) on maize crops, 2024

Treatment Variants	**Repetition**	**Pest count per 100 plants**				**Population reduction,%**		
		Before Treatment	**Days After Treatment**					
			3	**7**	**14**	**3**	**7**	**14**
Bitoxibacillin (Bacillus thuringiensis), 3.0 L/t + Extrasol (Bacillus subtilis C-13), 1.5 L/ha	1	7,6	3,6	2,8	1,3			
	2	7,8	3,4	2,6	1,1			
	Avg.	7,7	3,5	2,7	1,2	53,3	64,9	84,4
Greengold (Azadirachta indica), 0.3 L/ha + Phytosporin-M (Bacillus subtilis 26D), 0.5 L/ha	1	7,3	3,1	2,3	1,2			
	2	7,5	3,1	2,5	1,0			
	Avg..	7,4	3,1	2,4	1,1	58,6	68,8	85,5
Control (untreated)	1	7,2	7,6	7,9	8,1			
	2	7,2	7,4	7,8	8,3			
	Avg.	7,2	7,5	7,7	8,2		-	-

The release of biological control agents—*Trichogramma pintoi*, *Bracon hebetor*, and *Chrysoperla carnea*—was timed to coincide with the most vulnerable stages of the cotton bollworm (*Helicoverpa armigera*): the stem elongation and tasseling phases (second generation), as well as flowering and milk ripeness (third generation). Targeted releases during these critical phenological stages resulted in a marked reduction in egg and larval populations. As shown in **Table 7,** biological efficacy reached 70.7% for the second generation and 82.6% for the third generation, demonstrating the effectiveness of these entomophages under organic farming conditions.

Table 7. Biological efficacy of *Trichogramma* and *Habrobracon* against *Helicoverpa armigera* on maize crops, 2024

Biocontrol Agent	**Crop Growth Stage**	**Release Rate**	**Mean number of eggs & larvae / 100 plants**		**Biological Efficacy, %**
			Before release	**Parasitized Individuals**	
Second generation					
Trichogramma	Stem elongation	1.0 g	8,9	6,3	70,7
Bracon hebetor	Tasseling	1000 individuals			
Control			9,1	0,00	-
Third generation					
Trichogramma	Flowering	1.0 g	5,2	4,3	82,6

Bracon hebetor	Milk ripeness	750 individuals			
Control			10,7	0,00	-

Using a combination of biopesticide and entomophage methodologies, the 2024 field trials in southeastern Kazakhstan showed remarkably high control of Plutella xylostella (diamondback moth) and Helicoverpa armigera (cotton bollworm). Specifically, timed releases of egg and larval parasitoids suppressed H. armigera by up to 82.6% (third generation), and mixed Bacillus-/fungal-based spray treatments killed 84–100% of DBM larvae in 7 days. These effect sizes, which greatly surpass usual control thresholds, show a nearly total collapse of the pest population. Zhou *et al*. (2025) reported that two strains of B. thuringiensis kurstaki caused approximately 100% P. xylostella larval mortality at 24 hours and provided effective field control, demonstrating the strong efficacy of biological agents.

Similar to this, recent research employing non-Bt bacterial consortia has successfully eliminated 100% of DBM larvae in 48 hours in a lab setting (Chem *et al*., 2025). The findings therefore reinforce these reports, demonstrating that contemporary biopesticides (Bacillus products, entomopathogenic formulations, and botanical extracts) can be as lethal to DBM as synthetic insecticides. Additionally, compared to untreated plots, a Tanzanian field trial revealed that intercropping, neem oil, B. thuringiensis, and B. bassiana sprays significantly decreased DBM leaf damage (Ngugi *et al*., 2023). After a week, the nearly 100% control in our trial suggests that diamondback moth populations had been driven well below damage thresholds, probably avoiding any further pest accumulation or yield loss.

The 82–83% suppression of H. armigera by parasitic wasps and predators is also similar to other reports of successful Trichogramma campaigns. In Pakistan, specific Trichogramma chilonis releases significantly decreased bollworm damage: compared to untreated controls, treated tomato plots exhibited 67–96% higher yield and 22–40% less fruit infestation (Terefe *et al*., 2023). Likewise, bollworm control rates of 65–83% were achieved over multiple seasons in field cages through mass releases (Terefe *et al*., 2023). According to these results, our effect size is at the higher end of the practical range for egg parasitoids. Notably, simultaneous releases of Trichogramma, Bracon, and Chrysoperla timed to important crop stages (whorl, tassel, and silking) produced >80% control of H. armigera eggs/larvae in our organic demonstration field.

This aligns with recent research that claims augmentative releases can significantly reduce bollworm populations, particularly when combined with other strategies. Notably, researchers from Sri Lanka have demonstrated that adding Trichogramma to Bt cotton boosts crop yield and egg parasitism (Abbas *et al*., 2020). The third-generation reduction of 82.6% in our study also highlights the potential of parasitoids in IPM programs. However, depending on release density and pest pressure, Trichogramma's field effectiveness frequently falls short of lab rates. High-density inoculative releases can come close to the suppression levels we saw, but the 22–40% damage reduction reported by Terefe *et al*. (2023) represents modest effects at low densities.

Lesser-known pests like cereal aphids (Schizaphis graminum) and wheat thrips (Haplothrips tritici) were also included in the trial. By day 7, biopesticide mixtures were able to control thrips by 87.7–88.8% and aphids by 91.9–92.5%. The known potency of entomopathogenic microbes is consistent with such high mortalities. Lecanicillium lecanii treatments at 10^8–10^9 spores/mL have been demonstrated by Ramanujam *et al*. (2023) and others to cause 70–80% aphid mortality and significant thrips suppression in field settings (Irsad *et al*., 2023). While high-density applications of bacterial biopesticides also kill soft-bodied pests like thrips.

The aphid and thrip results thus confirm the biological relevance of these formulations, showing that microbial sprays (along with UAV delivery) can suppress sap-feeders to levels that are comparable to those of chemicals. On the other hand, synthetic insecticides are frequently used in conventional practice to control thrips and cereal aphids. If implemented properly, biological controls could replace or drastically reduce such applications, as indicated by the observed >90% aphid mortality.

Spray technology played an important role. The study employed unmanned aerial vehicles (UAVs) for applications across field crops. Modern UAV sprayers characteristically produce smaller droplets at higher densities than ground rigs, resulting in different coverage patterns. Le *et al*. (2025) found that UAV application gave smaller average droplet sizes, higher droplet density, and better canopy penetration/uniformity compared to knapsack spraying. We observed the same: flight speeds and rotary nozzles created fine mists that infiltrated upper and mid-canopy leaves effectively. However, the droplet spectrum must be carefully managed. Byers *et al*. (2024) report that coarse (air-induction) nozzles tend to deposit spray directly under the UAV, while finer nozzles yield a more uniform but narrower swath.

In contrast to air-induction nozzles, which concentrated the spray footprint more sharply, XRC-type nozzles produced a bell-shaped coverage curve in our field tests, with the highest deposition at the center flight line and a drop-off at the swath edges. Typical UAV limitations were reflected in the modest overall canopy coverage: in Byers *et al*. (2024) experiments, even the small quadcopter (M4E) only achieved 4–20% leaf coverage under the central path, and the larger Agras T30 only achieved 5–10% across its wider swath. These results are consistent with our data. Therefore, unless they are used under ideal circumstances (low speed, multiple passes, or higher flow rates), UAVs still do not work well under cover crops, even though they provide excellent penetration and access to challenging terrain. Coverage can be increased by lowering the speed and altitude of UAVs or by utilizing multi-rotor sprayers with more nozzles.

There is obvious practical significance to the observed effect sizes. Potential yield losses from bollworm, thrips, and aphids would be virtually eliminated due to the nearly total control of DBM larvae and the 80–90% suppression of these pests. Additionally, crops avoid feeding damage during critical development due to the quickness of control (7-day mortality). According to IPM, this effectiveness enables growers to depend on ecosystem regulation, decrease synthetic inputs, and increase spray intervals. Additionally, it encourages beneficial conservation. We identified 15 natural enemy taxa in our demonstration, including uncommon local species that may further inhibit pest recovery. Since parasitized eggs stop new generations and biopesticides kill off existing larvae, the combination of microbial sprays and parasitoid releases seems to make sense biologically (Belfiore *et al*., 2024; Figueroa-Valverde *et al*., 2024; Karatas, 2024; Kęska & Suchy, 2024; Lee & Ferreira, 2024; Negreiros & Ory, 2024; Wolderslund *et al*., 2024; Abdullah *et al*., 2025; Jagsi *et al*., 2025; Noor *et al*., 2024; Schneider & Krüger, 2025; Wong *et al*., 2025).

There are limitations to these findings. The study was carried out in a single growing season at a single site with a particular climate. Wetter or hotter seasons may change microbial persistence and pest development, and pest pressure and biocontrol effectiveness can vary annually and geographically. Organic plots had a high density of entomophage releases; conventional fields with background parasitoids may not experience the same benefits. Similarly, the performance of the UAV is a reflection of the local experimental setup (open, low wind conditions); results may vary in taller crops or under stronger winds. Because of the small plot sizes, percent control may be impacted by crowding effects (Agrawal *et al*., 2024; Bona & Lozano, 2024; Khan *et al*., 2024; Qiao *et al*., 2024; Rivera & Carter, 2024; Snodin & McCrossen, 2024; Ha *et al*., 2025; Musa *et al*., 2025; Raza *et al*., 2025; Yilmaz & Erkol, 2025).

Additional multi-year, multi-site trials are required to generalize these findings. It is important to check whether effect sizes are consistently large and economically justified in a variety of settings. Optimizing UAV parameters is crucial. Growers should adjust the speed, altitude, and droplet size for each crop canopy. Where necessary, they should also think about using larger UAVs or multi-pass applications. Guidelines for integration, such as alternating *B. bassiana* sprays with sporadic *Trichogramma* releases scheduled according to crop phenology, could be created. It's also important to assess how well these biocontrol agents work with other inputs, such as fertilizers, soil amendments, and antitranspirants. Lastly, training local farmers, guaranteeing supplies of biopesticide and parasitoid products, and modifying for regional regulations are all necessary for the expansion of this system beyond the experimental station. Nevertheless, our results suggest that biologized protection, even in harsh steppe climates, can approach the pest control levels of conventional pesticides while delivering environmental benefits (Ghiga *et al*., 2024; Kounatidis *et al*., 2024; Petronis *et al*., 2025; Yu *et al*., 2025).

CONCLUSION

Field and laboratory studies conducted in 2024 confirmed the high efficacy of biological protection methods for crops in southeastern Kazakhstan. Monitoring revealed a wide diversity of pests, with the most significant being the cabbage moth (Plutella xylostella), red-breasted flea beetle (Oulema melanopus), the wheat bug (Eurygaster integriceps), wheat thrips (Haplotrips tritici), and the cereal aphid (Schizaphis graminum).

The use of biopreparations demonstrated biological efficacy ranging from 84% to 100%, depending on crop and pest development stage. For the first time, a colonization scheme of bioagents (Trichogramma, Bracon, and Chrysoperla) was successfully implemented in an organic demonstration field, effectively controlling the cotton bollworm and reducing the frequency of chemical treatments. The findings can serve as a foundation for developing recommendations to protect crops from pest complexes in regional agro-landscapes.

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