Combating the Devastating Effects of Cotton Bollworm: Case of Uzbekistan

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Keywords: Bollworm; Cotton crops; Uzbekistan; Integrated pest management; Sustainable pest management.

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Introduction

Cotton production is a major agricultural sector involving over one hundred countries worldwide. Major cotton-producing countries, including India, China, the United States, Brazil, and Pakistan, grow cotton on about 35 million hectares and produce about 27 million tons of cotton fiber annually (www.theworldcounts.com, 2022). Effective control of pests and diseases through biological, chemical, and agrotechnical methods is critical to ensuring high-quality and abundant cotton harvests, as well as protecting various other crops (Mollaee et al., 2019). However, the increasing insect population worldwide poses a major challenge to the environment and biodiversity (Roy et al., 2023). Each year, a significant portion of global crop production, ranging from 20% to 40%, is lost due to pest infestations. The Food and Agriculture Organization of the United Nations reports that plant diseases alone result in a staggering $220 billion economic loss annually, while invasive insects account for an additional $70 billion. Weeds also pose a significant biotic constraint on global food production (www.unfoundation.org: November 2022). Protecting human health, meeting global agricultural needs, preserving the environment, and protecting crops from pests have therefore become urgent priorities (UN Climate Change). Urgent tasks include the expansion of biological laboratories, the widespread application of biological methods, the timely implementation of agrotechnical practices, and the study of the effective use of selective chemical preparations. Among the numerous insect pests, the cotton bollworm (*Helicoverpa armigera*) stands out because of its omnivorous feeding habits and the significant damage it can cause. The scientific importance lies in the research of preventive measures against the bollworm, such as the use of pheromone traps and artificial butterfly traps (Li et al., 2022; Melikuziyev et al., 2022). Currently, the use of biological means to protect cotton and other crops is extensively practiced in three regions of the Fergana Valley in Uzbekistan. However, the effectiveness of the use of Trichogramma, Bracon and Golden Eye entomophages is influenced by human factors, so research is needed to improve the efficiency of biological methods and to develop scientifically sound agrotechnical measures for bollworm control (Yuldasheva et al., 2022). Therefore, conducting scientific research in this area is of utmost importance.

This study, conducted under the priority research project*“Agriculture, Biotechnology, Ecology and Environmental Protection”* , falls under the initiative to promote science and technology in Uzbekistan (www.lex.uz). The study focuses specifically on cotton fields in Uzbekistan, particularly in the Fergana region, and is a case study based on practical research. The main objective of this study is to improve the effectiveness of bollworm control in the Fergana region by optimizing protection means, methods, and associated costs. Proposals are also made for the development of a comprehensive control approach that includes agrotechnical measures. The study focuses on companion crops heavily affected by bollworms, such as cotton, corn, tomato, pea, and sunflower. It examines the methods and means of an integrated protection system used to protect cotton from bollworm infestation. While numerous scientific studies on bollworm control are being conducted in cotton-growing countries, comprehensive research addressing existing challenges, optimization of control agents and methods, consideration of associated costs, and improvement of the overall control system by incorporating agrotechnical measures is still relatively unexplored in the Fergana Valley.

Theoretical Background

The study of bollworm control in cotton production includes several theoretical frameworks and approaches that provide a solid foundation for understanding and managing insect pests (Prasanna et al., 2022). Integrated Pest Management (IPM) is an important theoretical framework for bollworm control. It emphasizes ecosystem-based strategies that integrate biological, cultural, and chemical methods of pest control while minimizing environmental impacts. Implementing the principles of IPM reduces reliance on chemical insecticides, promotes natural pest control mechanisms, and improves the long-term sustainability of cotton production systems (Ortega-Ramos et al., 2022; Jowett et al., 2022). The study's focus on implementing an integrated protection system is consistent with the principles of IPM and reflects a holistic and environmentally conscious approach to bollworm control (Ortega-Ramos et al., 2022). Agroecology is another relevant theoretical framework that emphasizes the intricate interactions among crops, pests, and the broader agroecosystem. By promoting ecological processes, agroecology aims to create resilient and balanced agricultural systems. Integrating agroecological principles into bollworm management includes using natural enemies, promoting biodiversity, improving soil health, and diversifying habitats. The study's focus on optimizing agrotechnical measures and developing comprehensive control methods demonstrates the integration of agroecological concepts in bollworm control.

The concept of ecological resilience is highly relevant to the bollworm control study. Ecological resilience refers to the ability of an ecosystem to withstand disturbance while maintaining its structure and functions (Schneider et al., 2022). Building ecological resilience in crop protection means promoting biodiversity, reducing pesticide use, and strengthening natural biological control mechanisms. By introducing measures that increase the resilience of cotton fields to bollworm infestation, such as incorporating biological agents and using agrotechnical practices, the study is consistent with the overall goal of improving the ecological resilience of agricultural systems (Kamburova et al., 2022).

The field of pest management is being shaped by several emerging trends and studies that have implications for cotton worm control. These include advances in biological control methods, such as the use of genetically modified organisms (GMOs) or RNA interference (RNAi) technology to control bollworms (Hilbeck et al., 2020; Fu et al., 2022). In addition, studies examining the effects of climate change on insect pest dynamics and exploring strategies for climate-smart pest management provide valuable insights for adapting bollworm control measures to changing environmental conditions. By considering these emerging trends and incorporating relevant research findings, the study contributes to the ongoing discourse on innovative and sustainable approaches to bollworm control.

In addition to these established theoretical frameworks and emerging trends, the inclusion of an ecofeminist approach to the study raises critical questions about the environmental and social impacts of bollworm control. Ecofeminism explores the connection between the oppression of women and the destruction of the natural world (Tong, 2022). The use of chemical insecticides in bollworm control can have harmful impacts on ecosystems, including soil and water contamination and harm to non-target organisms. These ecological impacts disproportionately affect marginalized communities, particularly women who rely heavily on natural resources for their livelihoods (Barthold et al., 2022). An ecofeminist perspective emphasizes the need for alternative, non-hierarchical approaches to pest management that prioritize ecological harmony and social justice (Ahmad & Yaquub, 2022). It encourages the exploration of sustainable, community-based practices that empower local communities and promotes women's participation in decision-making (Juraev & Ahn, 2022). It also emphasizes valuing traditional ecological knowledge and indigenous practices in pest management (Juraev, 2022).

Incorporating ecofeminist concerns into the study of bollworm control leads to a critical examination of the social and environmental impacts of current control methods and encourages the exploration of alternative approaches that prioritize the well-being of both ecosystems and marginalized communities. By incorporating an ecofeminist perspective, the study contributes to a more comprehensive and socially just understanding of bollworm control in cotton production.

Ecofeminism as an interdisciplinary field includes the work of various scholars and activists such as Vandana Shiva (2014), Maria Mies (2014), Carolyn Merchant (2020), and Val Plumwood (2001). Notable works such as Shiva's “Staying Alive: Women, Ecology, and Development” (2016) and Mies' “Patriarchy and Accumulation on a World Scale” (2014) address the interconnectedness of gender, nature, and social justice (Tong, 2022). The ecofeminist approach is increasingly recognized as a valuable framework for analyzing environmental problems and advocating for transformative change (Szopa, 2022). In the specific context of bollworm control in Uzbekistan, the ecofeminist approach offers insights into the socio-environmental impacts of current practices and contributes to the development of alternative and sustainable pest management strategies (Yusupova & Gapparov, 2020). While the applicability of ecofeminist approaches may vary depending on local context and cultural factors, the principles of ecological harmony, social justice, and community empowerment are universally relevant (Winston, 2022). Incorporating ecofeminist concerns into the study of bollworm control in Uzbekistan illuminates the gendered dimensions of pest management and promotes inclusive decision-making processes that prioritize the well-being of ecosystems and marginalized communities.

Methods and Findings

Rigorous methods from entomology, agricultural entomology, and agro-toxicology were used in the study. Data obtained from laboratory experiments and small and large field trials were subjected to statistical analysis using Microsoft Excel based on the dispersion method.

The research presents several important scientific findings. For the first time, field experiments were conducted using agrotechnical measures in cotton production. A comparison with fields where wheat was planted between cotton rows showed a 25% reduction in bollworm numbers. A comparative analysis between fields where cut growth sites were left between cotton rows and fields where litter was collected and removed showed that the latter approach had higher efficiency, with bollworm infestation reductions ranging from 36% to 42%. The use of mineral fertilizers and chemical control agents against bollworms in cotton management showed the potential to increase yields by up to 63.7%. Monitoring with pheromones contributed to a 30-40% increase in biological efficiency. Determining optimal timing for science-based chemical treatments resulted in an additional 3.2 quintals of crop per hectare and an economic benefit of 442,000 UZS (or USD 400).

Acceptable efficacy against bollworms and sucking pests were achieved with Duet (55% emulsion concentrate) at a rate of 1.5 L/ha and Progress Plus (44% emulsion concentrate) at the same rate. Agrotechnical interventions such as fall plowing, salt washing, cultivation, provision of local and mineral fertilizers, retailing, and irrigation were evaluated for their acute and subsequent effects on cotton crops. Practical recommendations were made that resulted in a decrease in cotton seed loss from 10-12% to 80-90%. The organic method based on pheromone traps (pheromone monitoring) showed increased efficiency resulting in an additional yield of 1.4 quintals per acre, an increase in cotton product value of $1.53 for every dollar spent on protection, and an increase in profitability to 153%.

Thus, by following the scientifically recommended periods for active bollworm control, the use of emamectin benzoate, indoxacarb, and methomyl during the presence of medium and large juvenile worms resulted in an additional yield of up to 5 quintals per acre. The scientific significance of these research results lies in the evaluation of the seasonal development of the bollworm, its role in agro-biocoenoses, and its links with arthropods under the climatic conditions of the Fergana Valley (see also, Shokirova & Abdullaeva, 2020; Nazirkulomovna, 2022). The damage caused by bollworms to cotton crops and the effectiveness of various control measures, including both biological and chemical approaches, contribute to the integration of various tools into a comprehensive protection system. From a practical perspective, the research results are important for understanding the importance of each measure used in cotton agronomy to control bollworms. The effective use of bio-methods, insecticides, and the evaluation of pheromone monitoring and other physical-mechanical methods were demonstrated. Based on scientific research, practical recommendations were developed to increase the effectiveness of cotton protection against bollworms and to optimize the associated costs.

Consequently, a recommendation entitled “Modern control system against cotton bollworm” was published for the protection of cotton and other infested crops in the regions of the Fergana Valley (Tilyabaev et al., 2018; Nazirkulomovna, 2022). Application of recommended doses of Entovant, Entovant PRO (0.2-0.45 liters/kilogram per hectare), ”Prokleim”, ”Emamek” and ”Emaben Surender” has achieved an acceptable level of protection and resulted in an additional yield of 3-4 quintals per hectare. Successful implementation of these measures on certain farms in Toshlok District and Oltiarik District resulted in yield increases from 2.5 quintals/hectare to 4.0 t/ha. A total of 5560 hectares of cotton fields in the Fergana region benefited from the application of the active ingredients Entovant, Entovant PRO (0.2-0.45 liters/kilogram per hectare), Proklam, Surender, and Abamectin at a rate of 0.35 kilograms/hectare. This resulted in the economic efficiency of 2,176,000 UZS (approximately $200) per hectare compared to the average control and 1,900,000 UZS (approximately $170) compared to the standard treatment (Decis 2.5% e.m.g. at a rate of 0.7 liters/hectare).

The cotton bollworm and its control: bioecological definition and damage.

The cotton bollworm, which belongs to the butterfly family (Lepidoptera) Noctuidae, is a widespread insect species on Earth. There are over 200 species of bollworms in Central Asian countries, including various aphids that damage cotton and other crops. The most widespread and destructive species is the cotton bollworm. Because it feeds primarily on cotton bolls, the insect is commonly referred to as the "cotton bollworm" (see Figure 1). This pest is found in many countries around the world, including Indochina, the Middle East, Africa, South America, and the eastern part of Australia. The family Noctuidae includes more than 35,000 known species of moths, making it the most widely distributed horned caterpillar species in the world (Malinga & Laing, 2022; Alam, 2022). Consequently, numerous studies have focused on these pests in Uzbekistan. For instance, in experiments conducted between 1985 and 1990, Uzbek scientist M.I. Rashidov recorded 51 species of pests from 15 families of "Solanaceae". Among them, six aphid species were identified as harmful to tomatoes. Rashidov's research also revealed that 17 species from the Lepidoptera Noctuidae family were present in the agro-biocenosis and caused damage to agricultural crops. Rashidov emphasized that without the inclusion of entomophagous organisms, it is impossible to achieve 100% results in integrated pest management for agricultural crops. In cotton production alone, entomophagous organisms have an efficiency of 85-90% and reduce pest populations below economically harmful levels (Rashidov & Khodzhaev, 2000).

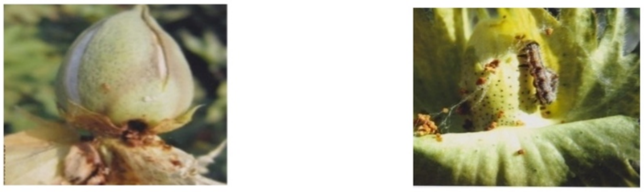
female (♀) and male (♂) butterfly species

an egg laid on a leaf

drying of damaged gossypium hirsutum

damaged cotton boll

damage of gossypium hirsutum



internal view of the damaged cotton boll

cotton boll worms

Figure 1. Cotton bollworm, life forms and damage to cotton(Figure prepared by the author).

1 – female () and male () butterfly breeds; 2 – an egg laid on a leaf; 3 – drying of the damaged bone; 4 – damaged cyst; 5 – damage to the comb; 6 – internal view of the affected cyst; 7 – nightshades.

Those relying solely on chemical protection methods cannot achieve such high efficiency. Moreover, long-term observations by scientist Khojaev Sh., have shown that a single cotton crop in Uzbekistan is damaged by 14 species of underground and above-ground ants and seven species of tomato root-gnawing ants (Gofurjonovich & Ibodullaevna, 2022). In particular, the autumn moth and the night moth contributed most to the damage. The bollworm is particularly prevalent in Central Asia and southern regions of Russia, causing significant damage to agricultural crops (Muhammadzikirovna, 2022). In Uzbekistan, it causes damage to cotton plantations in regions such as Surkhandarya, Kashkadarya, Fergana, Andijan, and Namangan. In recent years, it has increasingly infested cultivated areas in Bukhara, Khorezm, Karakalpakstan, and the Tashkent region. On cotton farms in the Andijan and Fergana regions of the Fergana Valley, bollworm is a recurring problem. Several factors contribute to this problem, including the cultivation of crops preferred by the bollworm (such as maize, vegetables, and legumes) on open land after grain harvest.

The cotton bug can also be classified as a significant insect. The adult butterfly has a wingspan of 30-40 mm and a body that ranges in color from yellowish-red to bluish-gray. On the upper side of the forewings, there is a round spot and a kidney-shaped black spot. The sexual development of the butterfly is incomplete after hatching from the cocoon, so additional feeding is required. These butterflies usually begin to fly in April or May when the soil temperature reaches 16°C at a depth of 10 cm. The butterflies lay their eggs primarily on the upper surface of leaves near the plant's growing point, either singly or in groups. The eggs have an apartment and round shape on the underside and measure 0.5-0.7 mm in diameter and 0.4-0.5 mm in length. They have 26-28 ribs, which are characteristic of solanaceous plants. Under magnification, the eggs look old and resemble empty containers when the trichogram flies emerge. Some eggs fail to hatch. The color of the caterpillar varies with diet and age, reaching 2.5-3.0 cm in length when fully grown (at about 5-6 years of age). The cotton bollworm goes through five molting stages during its six-year lifespan and builds a nest before each molt. The anal openings at the posterior end of the caterpillar body distinguish between female () and male () individuals (Figure 2). About 8-12 days after egg laying, the next generation of butterflies hatches from the buds. Under the conditions of Uzbekistan, the cotton bollworm goes through four to five generations per year, with three to four generations infesting cotton crops. Several experts have studied the cotton bollworm in detail, including its bioecological characteristics, distribution, target crops, the extent of damage, and methods of protection. In particular, the development of short- and long-term forecasting methods for annual cotton crop trends occupies an important place among these studies. Predicting the occurrence and density of bollworm generations in each field is a key issue in pest management, and scientists have developed several computational methods.

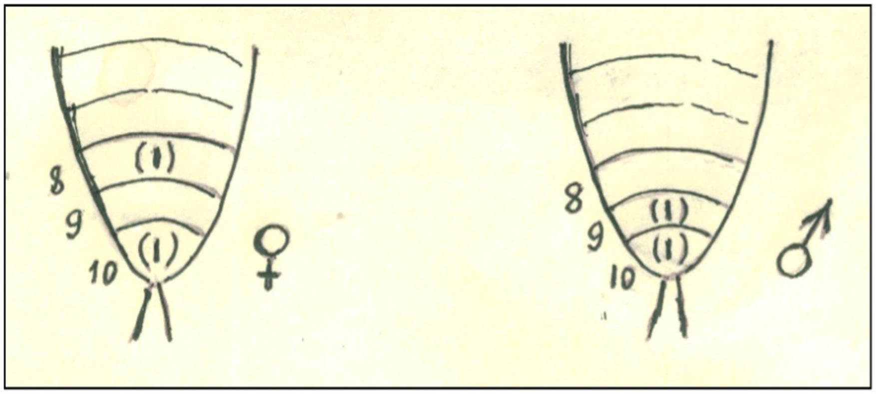


Figure 2. Cotton Bollworms: -female, - male (Author prepared the picture).

The most recent method used in practice was developed in 1959 Night Worms by a group of scientists from the Institute of Plant Protection in Uzbekistan. This method is based on a knowledge-based approach and uses data from the nearest meteorological stations for each region studied. The first-generation butterfly begins to fly when the temperature is constantly above 16°C at a depth of 10 cm in the uppermost soil layer. From this point, an effective temperature index is calculated by subtracting 11°C from the average daily air temperature. Once this sum reaches 550°C, the emergence of a new generation of butterflies is expected. Subsequent generations of bollworms are calculated using the same method (Joel, 2011).

According to this approach, the development of pollen worm populations in the following year is described as follows. The overwintering phase begins in August when the air temperature falls below 25°C. The survival of the bollworm during this period depends on feeding on young worms, namely cotton whose bolls have begun to open. The effective temperature is monitored during this period. If the average air temperature in autumn is between 11°C and 350°C, it means that the conditions are favorable for the pest to prepare for winter; otherwise, the conditions are considered unfavorable. The use of pheromone traps containing the cotton bollworm sex pheromone, introduced in Uzbekistan in the 1980s, cannot replace the need to predict the next generation of the pest or its density in the following year. These traps primarily indicate when the same generation of bollworms will emerge in the same field and provide information on population density (Tilyabaev et al., 2018). Despite advances in the methods described above, there are still unexplained occurrences that underscore the continuing need for scientific research. Cases such as the significant bollworm outbreaks in 1996 (Karadrina), 1988, 2004, and 2015-2017 in Central Asian countries remind us that scientific research is limitless. The cotton bollworm has a wide range of host plants, with more than 250 known species. The main food source is the fruiting stems of the plants, especially the bolls. However, the young worms initially feed on soft leaf tissue for one to two days. In Uzbekistan, cotton is the main host for the cotton bollworm, but it can also infest other crops such as corn, tomatoes, peanuts, squash blossoms, tobacco, hemp, peas, peppers, roses, and various other plants. In all plants and trees, there is excessive flower production on the stem, which gradually turns into fruit bud drop. The bollworm damage coefficient, a recently adopted criterion for the level of economic damage in Uzbekistan, indicates that an average infestation of 10 bolls per 100 bushels of cotton results in a yield reduction of 1 quintal. It is assumed that there are 10-12 young worms per 100 bushels of cotton. However, this indicator is from the past when agriculture was based on old economic relations. Since gaining independence in 1991, Uzbek agriculture has changed significantly with the introduction of a new system. Former relations have been broken, and new ones have emerged. Farmers now could change the criteria for economic damage caused by pests based on yield. It is our responsibility to pave the way for the future.

The cotton bollworm has numerous natural enemies, including parasites and predators. Over 100 natural enemies of the bollworm, including parasites and predators, have been identified. In the early 20th century, the importance of the ectoparasite Bracon (Bracon hebetor Sau.) was recognized. The cocoon of bollworm eggs was studied extensively, including Trichogramma (Trichogramma sp.) and Bracon within the worm. In 1986, the genus Habrabracon was renamed Bracon. To ensure that the quality of Trichogramma produced in bio-labs and bio-factories meets the required standards, a state-approved model was created by the Uzbek Ministry of Agriculture Resources (www.agro.uz) and Ministry of Water Resources (www.water.gov.uz).

According to this model, the following criteria must be met for each female Trichogramma:

1. The number of eggs should not be less than 30.
2. The ratio of females to males should be 1.5:1.0 or 2:1.
3. The number of laying females should be at least 90%.
4. The viability of females is defined as 89%, and the number of non-viable specimens should not exceed 5%.
5. Females should survive at least 5-7 days at a temperature of 25-29°C.
6. At least 80% of moth eggs should be damaged.

Apanteles (Apanteles cossack) also plays an important role in the natural reduction of bollworm populations. Another species of Apanteles, Cotesia, has been described by researchers. I.A. Somov reported the presence of two species of ichneumon flies in the dome of the bollworm.

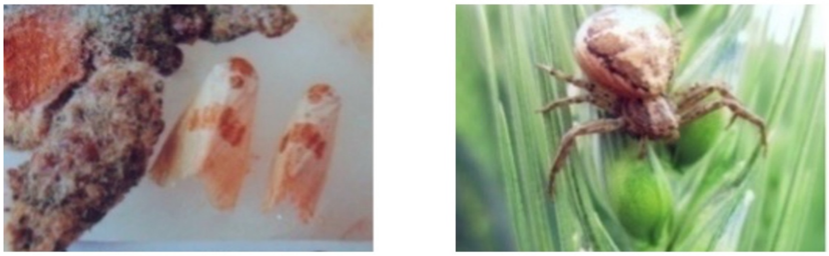
Beneficial Insects and Bio-Methods in Cotton Agro-Biocoenosis.

All living organisms have their own natural habits and food preferences. These preferences create a chain of interactions known as the “herbivore-pest-natural link” (see Figure 3). Insects can be divided into two food groups: Predators, which kill their prey quickly, and scavengers or “parasites”, which weaken their prey slowly. Predators such as goldeneye and ladybug larvae, dragonflies, damselflies, wasps, and squash bees are generally more effective. Among vertebrates, birds, especially sparrows, are very effective at controlling pests.

The caterpillar is on the cotton leaf

Apanteles cossack cocoon from the body of a cotton bollworm

Rare carnivorous shield-eating caterpillar on a peach trunk



Carnivorous shield-eating nightworm butterflies

Predatory spider

Figure 3. Examples of spiders found in agro-biocenosis(Prepared by the author).

1 – the caterpillar of the ladybug on a cotton leaf, 2 – the Apanteles Cossack spider, which emerges from the body of a cotton spider, 3 – a rare carnivorous shield-eating spider worm on a peach trunk, 4 – its butterflies, 5 – the significance of predatory spiders is different.

There are a considerable number of beneficial insects. According to Mansurov, over 50 different species of bollworms are used naturally. The total number of bollworm larvae exceeds 150. In this section, we will discuss some notable species (Khayitov et al., 2021).

(1) Apanteles kazak (Apanteles kazak Tel./Hymenoptera, Braconidae) is a specialized internal predator and collector of cotton tunnels. It is found throughout Uzbekistan and neighboring countries of Central Asia and the Transcaucasus. This small winged insect lays its eggs on the bodies of first and second-stage cotton bollworm larvae. The larvae of Apanteles kazak develop inside the bollworm larvae and eventually hatch as adults from the host's body segments. The bollworm survives only a few days before dying, while Apanteles kazak larvae hatch from the bollworm and spin cocoons within 30-40 minutes (www.pestworld.org).

(2) Bracon (Bracon hebetor Say.) and other butterflies are free-feeding larvae on the surface attacking the bollworm. In Uzbekistan, there are other species that target the intermediate and adult stages of the pest (see Figure 4). Historical literature even mentions Bracon and reports that cockroaches damaged 23-37% of cotton plants on farms in the Tashkent region in 1991 and 2002. In August 2011, 8.3-13.7% of nightcrawlers in cotton fields in the Pakhtabad district of the Andijan region were found to be infected with Bracon (www.pestworld.org).

Mature breeds of Bracon

Bracon: Larvae of the Paralyzed Nightworm and Cobweb

Figure 4. Bracon (prepared by the author).

1- mature breeds; 2- larvae of the paralyzed roundworm and the caterpillar.

(3) Bracon wasps (family Ichneumonidae) are large insects that parasitize cotton bollworm caterpillars. They lay their eggs on adult bollworms, from which larvae mature and hatch from the cocoon. These species have been discovered in Fergana, Andijan, Tashkent, and Surkhandarya regions (www.pestworld.org).

(4) Tachinidae (Gonia cilipeda Rd.), also known as "deer flies" (Chrysops sp.), are insects that live as parasites in other insects. Mature Tachinidae lay their eggs on leaves that are unknowingly ingested by feeding bollworm larvae. The hatched Tachinidae larvae then develop by consuming the internal contents of the host worm. Finally, the Tachinidae hatch from the bollworm's body after it has transformed into a fungus. This complex life cycle helps maintain balance in the insect world (www.pestworld.org).

(5) The lacewing (Chrysopa carnea Steph.) is an insect that belongs to the genus Chrysopa and is used as an effective natural control agent against cotton pests, including bollworms. The powerful jaws of the lacewing can kill significant numbers of young bollworm larvae. Among the entomophages in the cotton field bio-coenosis, the lacewing has the highest population density (see Figure 5). In order to mass produce this insect, it is bred in bio-labs and bio-factories. Lacewing larvae are omnivorous and will attack any living organism in their path, including eggs, larvae, fungi, and adult insects, regardless of species. However, lacewing propagation is difficult and expensive because they must be dispersed as live larvae to be effective (www.pestworld.org). (6) The egg-eating Trichogramma (Trichogramma pintoi Voegele.) is a small insect belonging to the family Trichogrammatidae, 0.3-0.9 mm long (see Figure 5). Trichogramma played an important role in introducing biological control and reducing the use of chemical insecticides against bollworms in Uzbekistan. There are 12 species of Trichogramma adapted to the climatic conditions of Central Asia and able to survive at high temperatures and low humidity. Trichogramma hibernates as "prepupa" in infected eggs and begins to hatch when the average air temperature rises above 8-10°C, which requires additional food. Male and female races of Trichogramma differ primarily in the number of joints in their antennae (5 joints in females and 3 joints in males) and the pubescence of males (sexual dimorphism). Trichogramma can lay between 1 and 60 eggs in each pollen egg, depending on the size of the infested egg. In Uzbekistan, Trichogramma lays an average of 2.1 to 2.4 eggs in each bollworm egg. At an ambient temperature of 30°C, Trichogramma eggs take about 1 day to develop into larvae, which then feed on the host (egg) contents for 2-3 days. After this stage, they hatch into the "prepupa" or pronymph, followed by pupation after 1.5-2 days. After darkening and maturing for 3-3.5 days, the infected egg becomes a mature Trichogramma. Whi-

le bollworm produces one generation (30-40 days), Trichogramma can produce offspring 2-3 times. In one season, there can be 12-14 generations. Trichogramma and Bracon are the main agents used against cotton bollworms and partially against fall bollworms. It is recommended that Trichogramma sylvetsin be applied at a rate of 1 gram per acre three to four times during each bollworm generation. When infestations are heavy and worms are present in the field, 200 to 2-3 thousand female Bracon individuals per hectare are applied, usually in mixed batches of males and females. However, the effectiveness of this approach may vary (www.pestworld.org).

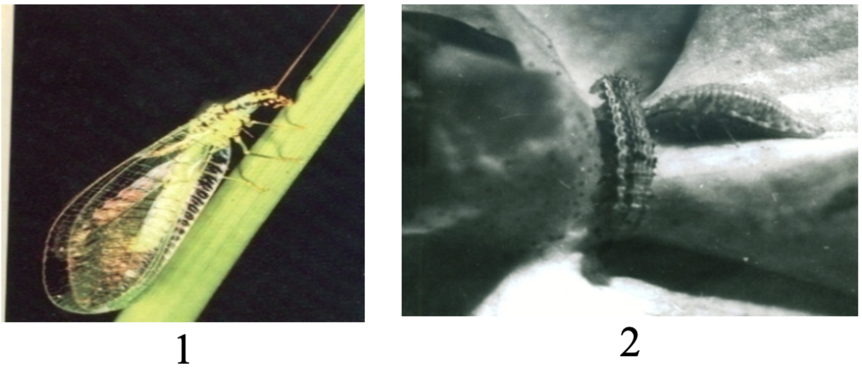


Figure 5. Trichogram (prepared by the author).

1) Mature breed; 3) Trichogramma-infested nightshade eggs.

The use of lacewings as a live insecticide against sucking pests and bollworms is often recommended. However, there are several things to keep in mind. First, lacewing egg application can be expensive. Recommended ratios for egg application are 1:1 for aphid, spider mite and cotton mite eggs, 1:10 for larvae and 1:100 for mature brood. Second, the efficacy of lacewing eggs can be problematic because they can be eaten by ants in the field. Field observations have shown an average of 300-350 ants per square meter of cotton bale in July. Considering these factors, it is advisable to release laboratory-bred lacewings near the fields, especially in the spring. Although the biological method is beneficial, there is a need in the field of entomology for more efficient and less toxic tools and methods. Therefore, conducting agro-toxicological research in Uzbekistan is of great importance. This research includes comprehensive testing and evaluation of pesticides from reputable chemical companies around the world, as well as domestically produced pesticides to ensure that they meet the necessary requirements. The research is conducted in accordance with the “Procedural Instructions” published by the State Chemical Commission under the Joint Stock Company “Uzkimyosanoat” (Chemical Industry) of Uzbekistan (www.uzkimyosanoat.uz).

Prevention of harmful organisms and organizational measures.

These activities are organizational measures to limit agricultural damage caused by pests, including bollworms, for the coming year without incurring additional costs. They also include measures to reduce the pest population. These measures include planning for the coming year, equipment maintenance, and spring work.

Agrotechnical control methods

Agrotechnical control methods play a crucial role in creating unfavorable conditions for pest development and favorable conditions for plant growth. Effective bollworm control measures include fall plowing, irrigation, cultivation, and application of organic and mineral fertilizers. Improving cotton cultivation techniques and studying their impact on bollworm development are important aspects of this approach (Nazarov et al., 2020).

Physical-mechanical methods

Physical-mechanical methods involve the use of various devices to reduce pest populations. Examples include the use of "bags" to control bollworms, the construction of pheromone traps that exploit the insect's sex pheromones, and the use of devices to collect insects in the field, such as traps that are attracted to light (Sorensen et al., 2016).

Use of biologically active substances

Biologically active substances are used to protect cotton crops. This includes the use of pheromone traps to control particularly harmful insects such as bollworms, fall bollworms, and crows. In addition, biologically active substances may contain attractants to lure insects or repellents to repel them (Malinga & Laing, 2022).

Thus, significant research has been conducted since the 1980s on the sex pheromone of the cotton cutworm, a pest that inflicts damage on cotton and other crops. In the 1990s, the use of sex pheromones for cotton and autumn cutworms became widespread. However, further research is needed in this area, as there are instances where the butterflies do not respond to the pheromone traps.

The Current Bollworm Control System.

It is important to emphasize that control measures that minimize damage are preferred. In this regard, experts aim to prepare the control of the bollworm by delaying its development for a longer period. Over the years, *"preventive"* treatments are ineffective in controlling pests. However, methods that reduce the number of pests in subsequent generations have proven effective. For example, research conducted in the fall focuses on reducing bollworm offspring by using low-consumption insecticides to poison the worms as they prepare for winter. A combined protection system has been established to control bollworms and other cotton pests. The main objective of this system is to restore the balance between beneficial and harmful arthropods in nature, primarily through non-chemical means. In the literature, "integrated pest management" is described as a protection system that combines various methods, including biological, chemical, agrotechnical, physical, mechanical, and quarantine methods. These approaches are used in conjunction with each other. Biological control methods take precedence in this framework. In Uzbekistan, Trichogramma species (family Trichogrammatidae) are widely used to control bollworm eggs. There are 12 naturally occurring Trichogramma species in Uzbekistan, which are found in various crops and ecosystems, especially in meadows. Trichogramma exhibits high reproductive potential in Uzbekistan, with 14-15 generations possible in a single season. These insects, active from May to October, are most abundant in July and August. Studies have shown that two species of Trichogramma are well adapted to climatic conditions in Central Asia. One species, Trichogrammatidae, thrives at high temperatures (30°C) and low humidity (30%), while the other, Hymenoptera, is still effective at temperatures of 30°C and humidity of 50%. In addition to these species, two other Trichogram species are recommended for use in Uzbekistan during the spring months: Tr. sugoniaevi Sor. (Hymenoptera) and Tr. evanescens Westw. (Richogramma evanescens Westwood). These species have shown a higher preference for air temperature and humidity (Kobiljonovna & Zaylobidinovna, 2022).

Currently, many insecticides are manufactured by large global pesticide companies, with smaller companies and ancillary players in the industry also involved in production. Many analogous products are available with identical active ingredients but different trade names. For example, there are 14 analogs of Detsis, 16 of Cypermethrin, 19 of Karate, and 9 of Emamectin Benzoate. Some of these products are manufactured and agro-toxicologically tested in Uzbekistan. Biologically active substances are between microbiological and chemical drugs. Among them, several substances with hormonal activity against bollworms (such as Dimilin, Eim, Sonnet, and Rimon) have shown promise in cotton research. However, their practical application remains limited. Biologically active substances also include the sex pheromones of certain insects. Many insects enter the mating season after hatching from their cocoons. This usually occurs 2-3 days after feeding on nectar from plant flowers, when their reproductive organs have developed. At this time, they release pheromones into the environment that signal their readiness to mate and attract insects of the opposite sex. Female insects usually release the sex pheromone.

The active ingredient in insect pheromones is the most important factor in their effectiveness. Even a small amount of pheromone, just a few molecules, can attract a male insect. Pheromones have multiple biological signaling properties and represent one of the most complex aspects of chemical ecology. Sex pheromones, trace pheromones, warning pheromones, territory marking pheromones, and eipheromones are the main types of insect pheromones. Insect sex pheromones were first isolated from the silkmoth (Bombyx mori) in 1959 (Abraham al., 1992). Since the 1970s, research on the isolation and identification of insect sex pheromones has intensified. By 1985, more than 350 insect species (over 160 in the former Soviet Union) were known to use sex pheromones worldwide. By the 1980s, the composition and major substances of bollworm sex pheromones were well documented (Tanskii, 1973). The composition of cotton bollworm sex pheromones consists mainly of major and minor substances, with Cys-11 hexadecenal accounting for 90% and Cys-9 hexadecenal accounting for 10% of the total composition. A mixture of these substances in a ratio of 9:1 is dissolved in an alcohol solution, which is then soaked in rubber tubes and distributed in kits for practical use. The recommended amount is 2 mg of the substance per rubber hose (one pheromone handle), and each rubber dispenser remains active for 15 days before being replaced by a pheromone trap.

Chemically synthesized pheromones that resemble natural pheromones are used extensively in insect biology and control research. Pheromone traps containing sex pheromones allow the study of insect phenology, developmental timing, and population dynamics. In addition, a control method that uses sex pheromones to trap bollworm moths and remove the pheromones from the females has been recommended. The use of pheromone traps for bollworm control has been scientifically established in Uzbekistan since 1983 (Khodzhaev, 1990). However, further scientific research is needed in this area. The cotton bollworm sex pheromone is a two-component compound chemically synthesized and developed by the Academy of Sciences of Uzbekistan Institute of Bioorganic Chemistry. Every year, cotton bollworm sex pheromone is newly synthesized, and its purity and activity need to be scientifically evaluated (www.biochem.uz). There are also new companies producing bollworm sex pheromones, and these products are being actively tested. In addition, the use of pheromone traps is critical for studying the effectiveness of applying trichograms in the field during specific time periods. A small rubber is inserted into a paper coated with adhesive, which is then impregnated with the pheromone substance and laid out in the field. The scent spreads with the wind and attracts male insects that become entangled in the adhesive. The effectiveness of the control methods depends on the number of moths caught in the glue traps.

In the fight against bollworms, the use of chemical insecticides undoubtedly plays a central role. In the past, various inorganic substances were used for this purpose until the 1940s, but their effectiveness proved to be minimal. During the war years, the development of insecticides such as DDT and organic hexachlorane compounds led to their worldwide use. In Uzbekistan, these agents were used extensively until the 1970s. After their ban, alternative agents were introduced to protect agricultural crops, including Polydofen, Fozalon, Phtalofos, Tsidial, Tsyanox, Kilval, Mezurol and others. During this period, new insecticides with minimal risks to warm-blooded animals and the environment were tested specifically for bollworm control (www.biochem.uz).

The properties of insecticides used in crop protection against bollworms are as follows:

1. Efficacy against insects and spider mites: insecticides are effective against both insects and spider mites, making them versatile pest control agents.

2. Low toxicity to beneficial insects: These insecticides have low toxicity to beneficial insects, so there is minimal interference with natural pest control mechanisms.

3. Short residence time in the environment: insecticides do not remain in the external environment for extended periods, minimizing their impact on non-target organisms and reducing the risk of accumulation.

4. Relative safety for humans and warm-blooded animals: the insecticides are relatively safe for human and warm-blooded animal health, further enhancing their suitability for crop protection.

During the study period, Sevin SL carbaryl, an insecticide with high efficacy against bollworms and lower risks to the environment and human health, was used extensively at a dosage of 2.5 kilograms per hectare. However, it was later found that this insecticide has long-term effects and can promote the reproduction of spider mites, so it is no longer used. In recent years, the insecticide Lannate, which belongs to the class of carbamates and is similar to Sevin SL carbaryl, has been tested in Uzbekistan. It is formulated as a water-soluble powder packaged in water-soluble sachets, providing a convenient application method. In the late 1970s and early 1980s, synthetic pyrethroids became the primary means of crop protection. Pyrethroids such as Ambush, Tsimbush, Sumitsidine and Detsis showed high efficacy against bollworms and other insects in preliminary trials. Residues in the plants were also investigated, as was the determination of appropriate pre-harvest waiting periods. Pyrethroids were then tested and recommended for bollworm control in various crops. Unlike natural pyrethrins derived from chamomile flowers, synthetic pyrethroids are chemically synthesized stable compounds that have high efficacy, are more resistant to sunlight, and have a rate of degradation compared to other insecticides. Several generations of synthetic pyrethroids have been developed. The first generation, including sumitcidin, ambush, tsimbush, and detsis, has primarily insecticidal properties. Subsequent generation pyrethroids, such as Tsibolt, Karate and Talstar, also have acaricidal properties and can control both insects and spider mites. Newly synthesized pyrethroids offer higher purity, lower consumption and reduced environmental risks compared to their predecessors. Examples include purified forms of sumicidin and Fastak (Alfagard), which contain specific isomers for improved efficacy (www.agro.uz).

Pyrethroids have several beneficial properties, including high biological efficacy, low consumption, minimal short-term environmental impact, no crop damage, and potential productivity enhancement. They are also relatively safe for beneficial insects, including bees, and adhere to soil and foliage without significant wash-off. However, negative properties include the potential for allergic reactions in humans and acute effects on certain stages of beneficial insects, as well as effects on aquatic animals.

Pyrethroids have shorter persistence in treated plants. Studies indicate that the active ingredient dissipates in cotton plants treated with various pyrethroids within 15-25 days, and no toxic residues are detected in seeds and plant oil. Synthetic pyrethroids represent a significant advance in the field of pesticides and offer high efficiency and safety in crop protection. However, continued research and development are needed to address the shortcomings of existing insecticides. Several insecticides or insecticide-acaricide mixtures, such as Nurell-D, Dadetsi, Deltafos, Endjeo, and Prempt, have been developed to overcome these limitations. Consequently, agro-toxicological evaluations are required for these new bollworm control agents (www.agro.uz).

The development of resistance in arthropods to insecticides is a drawback of chemical control methods. Resistance can arise from human activities or naturally within pest populations. It occurs when resistant genotypes in the pest population survive exposure to the applied pesticide, due to genetic factors and selection pressure. Resistance to various classes of insecticides has been observed worldwide, with numerous arthropod species exhibiting varying degrees of resistance. To combat resistance, researchers must explore the underlying causes and develop strategies to mitigate its effects. Resistance typically develops in heavily treated crops and in multigenerational arthropods. Historical examples of resistance include cases in Uzbekistan, where the efficacy of certain insecticides declined against cotton bollworms in the 1960s and against head lice (Pediculus humanus capitis) in the 1980s (www.biochem.uz).

In Uzbekistan, studies have focused on examining the resistance of cotton plants to insecticides. Although chemical control of bollworms in Uzbekistan was relatively lower than in neighboring Tajikistan and Azerbaijan, a decline in the efficacy of dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane, polychlorcamphene, and Dilor was observed in the 1970s. In Tajikistan, bollworm resistance reached 97-fold by 1976. Therefore, the risk of resistance development in bollworm in Uzbekistan, where pyrethroids were widely used, prompted us to investigate. The presence of resistance in populations of white-winged bollworm (possibly Earias insulana) served as the basis for investigating the sensitivity of different bollworm populations to commonly used insecticides. The cotton protection system in Uzbekistan uses an integrated approach that aims to increase the efficiency of crop protection while minimizing the use of pesticides. Unlike the previous system, which aimed to eradicate pests, the current system strives to maintain pest populations at levels that do not cause economic damage.

The integrated bollworm defense system was developed over several decades. Initially, efforts focused on reducing treatment frequency by establishing scientifically determined treatment periods. Over time, the system has evolved to include economically feasible volume criteria for evaluating the damage caused by bollworms. The previous criterion, which identified 10-12 infested bolls per 100 bolls, is being reevaluated due to changing economic circumstances, such as reductions in government subsidies for pesticide prices. The current system is adapting to the new economic dynamics, which requires a revision of the indicators of the level of economic damage caused by pests (www.agro.uz).

Case of Fergana Province

Natural Resources and Climatic Conditions

Research conducted in the Fergana region focused on the study of conditions and working methods related to bollworm control in the area. The Fergana Valley is located in a lowland plain surrounded on three sides by mountain ranges and has unique soil characteristics and a mild continental climate. The region comprises three areas, with the Fergana province occupying the southeastern part. In the northern part of the Fergana province is the Toshlok district (Figure 6), which is characterized by coastal cliffs that have significantly influenced the formation of the soil layer. The soil composition on the slopes consists of small and large stones, which leads to a low water storage capacity. Therefore, the gardens and plants in this area require frequent irrigation (up to 20 times).

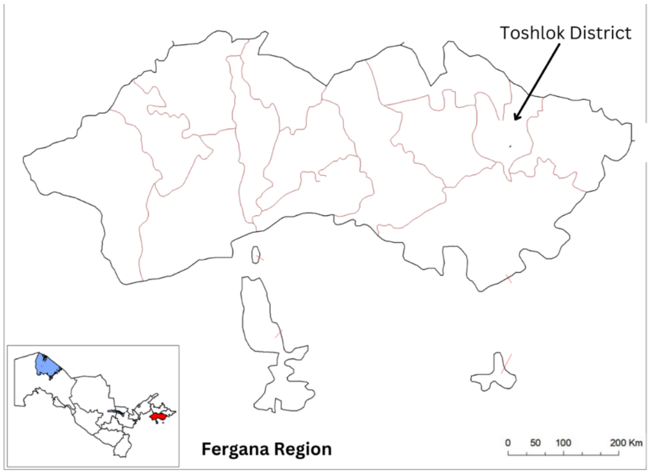


Figure 6. Map of Fergana region, indicating the Toshlok district (Author prepared).

The Fergana Valley is known for its soils, which are ideal for growing a variety of crops. In addition, the climatic conditions in this region provide favourable circumstances characterised by sufficient warmth, sunlight and humidity. The valley has a dry and continental climate that falls predominantly into the cool arid category, although some less protected areas have a cool semi-arid climate. In March, temperatures rise to around 20 °C or 68 °F and quickly reach 35 °C or 95 °F in June, July and August. Rainfall is sparse in the following five months from April, but its frequency gradually increases from October. December and January see snowfall and frost, with temperatures dropping to -20 °C or -4 °F. Analysis of climatic conditions showed an increase in precipitation, especially in the spring months. This increased precipitation had a positive impact on the availability of food and nectar for insects that emerge early in the season. Consequently, conditions in Toshlok district of Fergana region provide ample opportunities for cotton and cereal crops. These favourable conditions contribute significantly to the potential for increasing cotton production (www.gov.uz).

The research was primarily conducted on farms in the Toshlok district and in the laboratory. However, field research and observations were also conducted in the Khojaabad district of the Andijan region (Figure 7), particularly the "Surayyokhanum Orzusi" farm. This was essential to study the prevalence and susceptibility of bollworm populations in different parts of Fergana Valley. In the Toshlok district, most of the surveys were conducted in the fields of the “Sohibjon MMM” farm. This farm serves as a model farm and has shown successful cotton production, especially with the cotton variety “Sultan”.

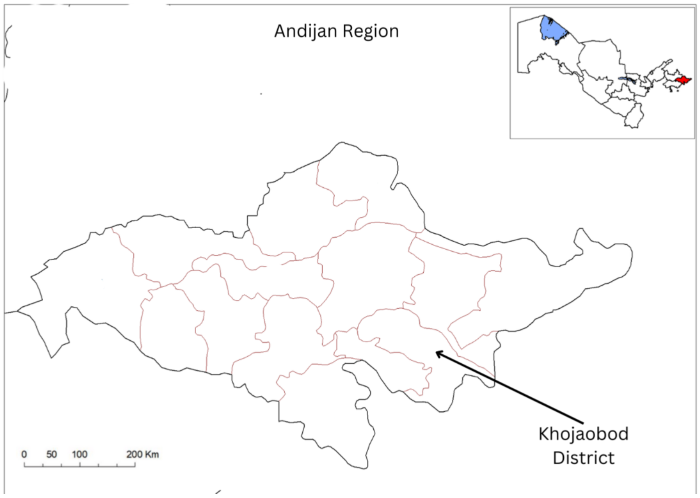


Figure 7. Map of Andijan region, indicating Khojaabad district(author prepared).

In this case, about 60-70% of the 11-13 bolls on each plant were open in the second ten days of September. Subsequently, 90-95% of the crop was harvested after the first and second cotton harvests. This allowed the planting of a replacement crop, such as cereals, in October. Farms in the district mainly use stony, gray alluvial soils with sandy texture and little organic matter with humus content between 0.45% and 0.7%. Therefore, the application of organic and cultural fertilizers is crucial to improve soil fertility in these sandy soils.

Method

Several methods from different fields were used in the study, including entomology, biology, morphology, ecology, and agro-toxicology. The method used in the study was cotton tunnel census and control. Biological control of cotton pests was carried out based on relevant publications. Insecticide tests against cotton bollworms were conducted, linking the effects of agrotechnical measures to cotton bollworm biology and cotton agricultural techniques. Methodological guidelines were used for testing pheromone traps and evaluating their effectiveness. An original method developed in the laboratories of the Crop Protection Institute was used to study the effects of insecticides on beneficial insects such as Trichogramma, Bracon, and Haddock.

The method involved the following steps:

1. Spraying the insecticide on plants in small field plots.
2. After a certain time, the leaves are cut off and stored in jars under laboratory conditions.
3. Evaluation of the effect of the agent after 24 hours.
4. Conduct these tests until the effect of the agent is no longer present or decreases by 30%.

The economic damage caused by bollworms was evaluated using the criterion of the amount of new economic damage. The biological efficiency of the insecticides was calculated using the generally accepted formula (Klare et al., 1995):

$BS = (Av - Va) / Av \times 100\%$, *where: BS - biological efficiency, A - the number of pests in the experimental variant before t*

The resulting data were statistically analyzed using various methods, including the ”limit” and scatter analysis methods. Specific recommendations were used to determine the economic and business efficiency of the methods and tools studied. These recommendations provided a framework for evaluating the cost-effectiveness and practicality of the approaches studied.

Chemical and Agro-Toxicological Properties of Studied Insecticides.

In this section, we briefly review the chemical and agro-toxicological properties of the insecticides studied. The insecticides studied include Detsis, Cypermethrin, Karate, Talstar, Avaunt, Proclaim, Lannet, Coragen, Teron Bio, and Nurell-D. These insecticides are widely used in various regions, including Uzbekistan, due to their effectiveness in controlling pests that attack crops and cause significant agricultural damage.

Deltamethrin, the active ingredient in Detsis, is a first-generation pyrethroid insecticide. It is highly effective against adult insects and rodent larvae and exhibits potent activity with low consumption. Deltamethrin is used worldwide and has gained popularity in Uzbekistan due to its efficacy and low dosage. However, it is important to know that deltamethrin is highly toxic to warm-blooded animals (Bhardwaj et al., 2020; Dilshod et al., 2023).

Cypermethrin, contained in insecticides such as Tsimbush and Tsirax, belongs to the first generation of synthetic pyrethroids. Since its introduction in 1981, it has been widely used to protect technical and vegetable crops, garden trees and pastures from various pests, except spider mites. Cypermethrin acts on insects from the surface and from within, without systemic effects. It is known for its moderate toxicity in warm-blooded plants and can be used against various pests in different crops and pastures.

Karate, which contains lambdacyhalothrin, belongs to the new generation of pyrethroids. It exhibits high activity and efficiency even at low concentrations. Karate is effective in controlling both insects and spiders, which makes it valuable for pest control in various crops. The highly toxic nature of lambdacyhalothrin should be considered during application.

Talstar, with its active ingredient bifenthrin, is an insecticide and acaricide developed by the American company FMS. Extensive testing has shown positive results, particularly in protecting cotton against spider mites, bollworms, aphids and thrips. Bifenthrin is highly toxic and requires careful handling to avoid adverse effects on warm-blooded animals.

Avaunt, which contains indoxacarb, belongs to a new class of chemical compounds known as oxadiazines. Avaunt is highly effective against butterfly caterpillars and poses minimal risk to non-target insects, including beneficial insects. The insecticide’s unique mode of action, based on blocking sodium channels in the insects’ nervous systems, causes them to stop feeding and subsequently die.

Proclaim, an emamectin-based insecticide, belongs to the chemical class of emamectins. Emamectin benzoate, the pure substance in Proclaim, has low toxicity to warm-blooded animals and humans while being highly effective against all stages of the cotton bollworm. It is particularly beneficial in controlling large young worms in the field (Nazirkulomovna, 2022).

Lannate, a carbamate insecticide with similar properties to the formerly widely used Sevin, contains methomyl as the active ingredient. It is slightly toxic and highly effective against adult insects and young worms. The application rate of Lannate is usually between 1.5 and 2.0 l/ha (Nazirkulomovna, 2022).

Coragen, an insecticide developed by DuPont, contains chlorantraniliprole as the active ingredient. This highly effective insecticide is effective against worms and has unique properties. When sprayed on plants, it is absorbed into leaf tissue and creates insecticidal cells in the leaves. Thank you to its ovicidal and larvicidal properties, Coragen is suitable for controlling insects that migrate by forming pores between leaf tissues. It also has lower toxicity to warm-blooded animals and non-target insects (Nazirkulomovna, 2022).

Teron Bio is derived from a plant that contains limonoids, a new group of pesticides. Limonoids, including azadirachtin, have been shown to disrupt certain hormonal processes in insects, preventing their metamorphosis and causing them to die. Teron Bio is virtually harmless to warm-blooded animals and humans (Nazirkulomovna, 2022).

In addition to the above single insecticides, mixed insecticide-acaricides have been tested to increase their efficacy against bollworms through synergistic effects. Organophosphorus compounds such as chlorpyrifos, “profenofos”, or “hostation” were used as synergists in these mixtures (Nazirkulomovna, 2022).

Nurell-D, a mixture preparation, contains cypermethrin (5%) and chlorpyrifos (Dursban) (50%). It has been widely produced and used since 1987 for its high efficacy against difficult-to-control pests such as tuber leaf fungi and spider mites. Nurell-D has moderate toxicity and is registered for cotton protection against aphids, thrips, spider mites, and bollworms (Nazirkulomovna, 2022).

Thus, the insecticides discussed comprise different chemical classes and exhibit different agro-toxicological properties. Although they are effective in controlling pests in different crops, it is important to consider their potential toxicity to warm-blooded and nontarget organisms when applying them. Proper selection and responsible use of these insecticides can make an important contribution to integrated pest management strategies and sustainable agricultural practices.

Findings

So, the case study provides an overview of various insecticides used in pest control and crop protection. The insecticides discussed, including Detsis, Cypermethrin, Karate, Talstar, Avaunt, Proclaim, Lannet, Coragen, Teron Bio, and Nurell-D, have different chemical compositions and agro-toxicological properties. Deltamethrin, as contained in Detsis, is a potent pyrethroid insecticide widely used worldwide and in Uzbekistan. Although it has potent efficacy against pests, it is highly toxic to warm-blooded animals. Cypermethrin, found in insecticides such as Tsimbush and Tsirax, is a first-generation synthetic pyrethroid known for its broad protection against a variety of pests. It has moderate toxicity to warm-blooded animals and can be used in various crops. Karate, which contains lambdacyhalothrin, represents a new generation of pyrethroids with high efficacy even at low doses. Talstar, with its active ingredient bifenthrin, has shown positive results in protecting cotton against certain pests. However, both Karate and Talstar require careful handling due to their high toxicity.

Avaunt, Proclaim and Teron Bio introduce innovative classes of insecticides. Avaunt’s unique mode of action and selective action on caterpillars make it suitable for integrated pest management systems. Proclaim, which is based on emamectins, effectively controls bollworm and has low toxicity to non-target insects. Teron Bio, derived from plant-derived compounds, is a safe alternative for pest control that poses no significant risks to warm-blooded animals. Lannate, Coragen and Nurell-D offer effective solutions against pests while taking safety considerations into account. Lannate, with the active ingredient methomyl, has been shown to be effective against adult insects and young worms. Coragen’s unique mode of action and translaminar activity make it suitable for controlling pests that migrate between leaf tissues. Nurell-D, a mixed preparation of cypermethrin and chlorpyrifos, effectively targets difficult pests and requires cautious use due to its moderate toxicity. Overall, the insecticides presented provide a range of options for agricultural pest control. Their selection and use should be based on careful consideration of their agro-toxicological properties, efficacy, and potential impact on non-target organisms. Implementing integrated pest management strategies and using pesticides responsibly can help ensure sustainable agricultural practices while effectively controlling pests and minimizing risks to the environment and human health.

Discussion

This study examined current trends, challenges, appropriate theoretical approaches, and struggles related to insecticide use in pest management, with a particular focus on incorporating ecofeminist concerns. By examining the current state of affairs and considering the broader context, this section illuminates the complexities and potential opportunities for improvement in this area. A major trend in the pest management world is the continued development and introduction of new generations of insecticides. The case study highlights the transition from first-generation pyrethroids, such as deltamethrin and cypermethrin, to newer classes, such as lambdacyhalothrin and bifenthrin (see also, Nazirkulomovna, 2022). These advances bring higher efficacy, lower use rates, and an improved safety profile, which is a positive development. However, it is important to recognize and address the potential toxicity of these insecticides to non-target organisms and the environment. This concern is consistent with ecofeminist perspectives that emphasize the interconnectedness of gender, nature, and social justice. Responsible use of pesticides and application of integrated pest management strategies (IPM) are important steps to minimize negative impacts on ecosystems and marginalized communities. Resistance in target pests continues to be a major challenge in practice. Continued exposure to certain insecticides can lead to the development of resistance, rendering certain active ingredients ineffective over time. Proactive resistance management strategies are needed, including rotation of insecticides with different mechanisms of action and implementation of monitoring programs for early detection of resistance. Consistent with ecofeminist concerns, these strategies emphasize the need for sustainable and socially just approaches to pest management that consider the well-being of ecosystems and marginalized communities.

It is also important to consider the impact of insecticides on beneficial insects such as pollinators and natural pest controllers. Maintaining a healthy and balanced ecosystem is critical to sustainable agriculture. Ecofeminist perspectives advocate for strategies that selectively target pests while minimizing harm to beneficial insects, with a focus on biodiversity and long-term ecological stability. The case study mentions insecticide use in Uzbekistan, where cotton is an important crop, demonstrating the importance of region-specific considerations. Understanding the unique pest profiles, climatic conditions, and regulatory frameworks in specific areas is critical to developing tailored and effective pest management strategies. This approach is consistent with ecofeminist considerations that emphasize the importance of local context and cultural factors in pest management decisions. To address the challenges discussed and improve the sustainability of pest management practices, collaboration and knowledge sharing among researchers, farmers, policy makers, and industry stakeholders are essential. Ecofeminist perspectives call for inclusive decision-making processes that empower local communities, including women, to shape pest management strategies. Investments in research and development of environmentally friendly alternatives, such as biological control agents and integrated approaches, can pave the way for more sustainable pest management systems. Sound risk assessment protocols and regulatory frameworks should be in place to ensure safe insecticide use and protect human health and the environment. By adopting sustainable practices, promoting collaboration, and addressing ecofeminist concerns, stakeholders can work toward effective pest management while minimizing potential risks and ensuring the long-term sustainability of agricultural systems. This integrated approach reflects a comprehensive understanding of the social, environmental, and gender dimensions of bollworm control and contributes to a more equitable and ecologically conscious agricultural landscape.

Conclusion

So, the bollworm (Helicoverpa armigera Hb.) remains a formidable threat to cotton crops worldwide, including those in the Fergana Valley of Uzbekistan. Extensive research has been conducted to understand and control this destructive insect, but there is an urgent need for continuous improvement of the overall control system. Factors such as declining net sensitivity and increasing reliance on insecticides have necessitated research into alternative approaches. The adoption of integrated pest management (IPM) is a promising and globally recognized strategy to address the challenges posed by cotton bollworm. Moving from the current general protection system to an integrated approach can reduce overuse of chemical inputs while achieving greater overall efficiency. IPM integrates a range of pest management methods that include biological, cultural, and chemical approaches in a holistic and sustainable manner. This comprehensive framework not only reduces bollworm infestations, but also protects the ecosystem balance by considering impacts on non-target organisms and conserving beneficial insects. In the diverse agricultural landscape of the Fergana Valley, bollworm exhibits a multigenerational life cycle, infesting a variety of crops including tomatoes, corn, peanuts, peas, and wheat. The overwintering phase of the larvae or pupae exposes cotton plants to significant damage in their later stages of development. Although natural bollworm populations exist, their density alone is often insufficient to achieve an economically viable level of control. Therefore, the use of artificial biological control methods and the targeted use of insecticides is essential, especially during periods of high bollworm density.

Looking to the future, it is important to adopt globally recognized approaches and trends in pest control. Integrated pest management, with its emphasis on sustainability and environmentally friendly practices, should be widely disseminated and adopted. Collaborative efforts among researchers, farmers, policymakers, and industry stakeholders are essential for sharing knowledge and developing innovative solutions. Continued refinement of control systems, application of integrated approaches, and incorporation of globally accepted practices can mitigate the harmful effects of bollworms and ensure the long-term sustainability of cotton production while minimizing environmental risks. Considering these findings, it is recommended that further research be conducted to explore advanced techniques and technologies that can complement bollworm control measures. This includes research into novel biological control agents, the development of resistant cotton varieties, and the implementation of advanced surveillance systems for early detection of bollworm populations. In addition, educational programs should be established to increase grower awareness of the benefits and proper implementation of integrated pest management. By combining scientific advances, global best practices, and active stakeholder participation, we can strengthen our defenses against bollworms and ensure agricultural productivity for current and future generations.

Declarations

Ethics approval and consent to participate.

This study did not involve human participants, and therefore, ethics approval and consent were not required.

Consent for publication

All authors have given their consent for the publication of this research article.

Availability of data and materials

There are no additional data or materials associated with this study as it is based on a comprehensive literature review and field observations.

Competing interests

The authors declare no competing interests.

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Authors' contributions

All authors contributed equally to the conception, design, data analysis, and writing of the manuscript.

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female (♀) and male (♂) butterfly species

an egg laid on a leaf

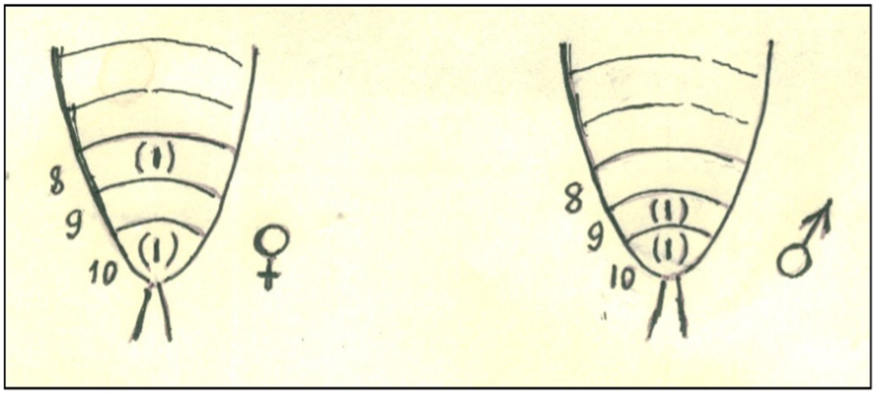
drying of damaged gossypium hirsutum

damaged cotton boll

damage of gossypium hirsutum

internal view of the damaged cotton boll

cotton boll worms



The caterpillar is on the cotton leaf

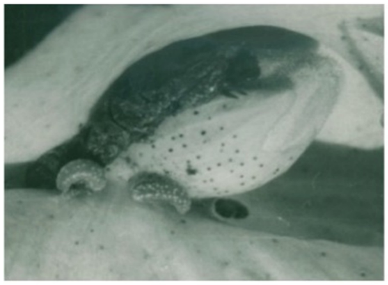
Apanteles cossack cocoon from the body of a cotton bollworm

Rare carnivorous shield-eating caterpillar on a peach trunk

Carnivorous shield-eating nightworm butterflies

Predatory spider

Mature breeds of Bracon



Bracon: Larvae of the Paralyzed Nightworm and Cobweb