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IMPACT OF CLIMATE CHANGE ON ARMYWORM INFESTATION AND HORTICULTURAL CROP PRODUCTION IN GILGIT-BALTISTAN

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ABSTRACT

The armyworm is one of the major threats to global food crop security. It is a polyphagous pest that has recently spread to Gilgit Baltistan (GB) from another region of Pakistan. This pest has posed a significant threat to economically important cereal crops like wheat and maize, as well as to vegetable crops such as beans, forage crops like berseem and alfalfa, and fruit trees. While it has been reported in other regions of Pakistan, there has been no confirmed presence of the armyworm in GB, Pakistan. In April 2022, the armyworm invaded crops in districts Gilgit, Nagar, Hunza, Diamer, and Baltistan region. To monitor its movement, the integrated pest and disease management (IPDM) department of GB established mechanical traps in these districts. The armyworm outbreak persisted in these districts until the end of June 2022. The field survey revealed that the pest primarily targeted wheat, beans, maize, berseem, clovers, forage grasses, and vegetables. Suspected armyworm moths were captured and identified as *Mythimna unipuncta* through morphological analysis. Various pesticides were applied in the aforementioned districts to manage the armyworms. Additionally, the farming community of GB was provided with mechanical traps and spray machines. The invasion of armyworms might be attributed to climate change, which has been observed over the last 4-5 years in GB. This case study confirms the first instance of armyworm immigration into GB, and it will serve as a valuable resource for the monitoring and management of armyworms. Moreover, raising farmer awareness about climate change and its impact on armyworms is essential. To effectively manage insect pests under changing climatic conditions, it is crucial to collaborate with stakeholders and farmers to prepare and enhance armyworm risk assessment maps. Furthermore, a comprehensive study involving molecular identification of the Fall Armyworm (FAW) should be conducted to achieve scientific identification.

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INTRODUCTION

Gilgit-Baltistan (GB) is the northern territory administered by Pakistan with a total area of 72,971 km^2 (Hussain et al., 2021). GB is most beautiful with fifty of the world's highest mountains and largest glaciers, linked to the Xinjiang region of China to the northeast and east, Azad Kashmir to the South, Khyber Pakhtunkhwa to the west, and Wakhan Corridor of Afghanistan to the north (Butz and Cook, 2011). Gilgit-Baltistan is divided into ten districts for its administrative purpose (Gilgit, Nagar, Hunza, Ghizer, Diamer, Astore, Skardu, Ghanche, Kharmang, and Shiger).

These areas have unique importance due to their diverse bio-physical environment and the vibrant cultural setting of the inhabitants belonging to hundreds of ethnic groups and indigenous communities moreover of flowering plants are found in Gilgit-Baltistan, some of which are globally important. Agriculture is the primary source of income for the people of GB, the important fruits are apricots, apples, cherries, peaches, pears, pomegranates, and grapes (Abbas et al., 2023). Tomatoes and potatoes are the main source of income and wheat and maize are the main cereal crops grown in GB (Husain et al., 2017a). The climatic conditions are ideal for growing fruits, vegetables, and grains, plant diseases and pests were absent in the region due to its unique climatic and geographic conditions. In Gilgit-Baltistan, Horticulture, including high-value fruit and vegetable crops, is the major source of subsistence. The land is fertile, but the prevailing challenging conditions and factors of small land holdings have prevented the farming communities from producing fruit and vegetables on a vast piece of land (Shahzad et al., 2021). Instead, fruit production has taken place on smaller pieces of land near fields used for cultivation or at the household level. As a result, relatively small quantities of fruit and vegetables have been produced throughout the area for centuries.

In Gilgit- Baltistan (GB), fruit flies, codling moths, mealy bugs, hairy caterpillars, white grub, and other pests are highly injurious to cereals, vegetables, and fruits. Most of the fruits, cereals, vegetables, and trees are grown on the lands along the water channels which are diverted from rivers (Abbas et al 2018). These pests have been considered the main constraints in improving horticulture in GB. For example, fruit flies continuously threaten peaches, plums, persimmon, pomegranates, and vegetables (Hussain et al., 2019).

The environmental changes due to climatic factors such as temperature rise and heavy rains cause more severe and catastrophic conditions and GB becomes vulnerable leading to severe diseases and insect infestations resulting in food insecurity for the people of GB.

The Armyworm (*Mythimna unipuncta* (Haworth 1809) is a serious agricultural pest worldwide. The larvae of the armyworms advance in a military column pattern, eating everything in their way. It lacks diapause despite being a multivoltine migrant insect of the family Noctuidae in the order Lepidoptera (Brou et al., 2020). Originating in the tropics and subtropics, it has been discovered in temperate zones as well. Without diapause, armyworm spends the winter in sub- and tropical climates, then moves north to temperate zones when the time is right. Among them, climatic factors, the temperature has a profound effect on all ectothermic species and, thus, on the life cycle, behavior, survival, and distribution of armyworms (Domingues and Ornelas, 2022). Due to abrupt changes in the climatic conditions, agricultural and horticultural crops, including wheat, beans, maize, berseem, clovers, forage grasses, and vegetables in many districts of GB, have been widely infested by armyworms (Rizvi and Jaffar, 2015).

The Department of Agriculture has started a comprehensive survey and found these pests in all districts of GB and started a comprehensive campaign for the control of armyworms simultaneously in all affected areas within the limited available resources to cope with the emergency arising from this pest Previously there was no report on the larval damage in GB province; the first immigration of armyworm and the possible source is still obscure. Here we reported the invasion of armyworms and applied different pesticides to control this pest. Furthermore, we are assisting the farming community regarding IPM techniques of armyworms and impart advisory services to the farmers regarding safe pesticide applications.

Geographical Distribution

The distribution of *M. unipuncta* spans across the Americas, certain regions of Europe, Africa, and Asia. Its native range is primarily concentrated in North and South America. However, it has been introduced from these regions to various other locations worldwide (Nagoshi, and Meagher, 2004). The name "armyworms" is derived from the behavior of their caterpillars, which exhibit a collective movement resembling that of an army. These caterpillars migrate in large numbers from one field to another, causing extensive damage to crops in their path (Westbrook et al., 2019). True armyworms exhibit distinct migration patterns, with a northward movement during spring and a southward migration in autumn which allow them to find favorable environments for mating during the summer season. Throughout their life cycle, which includes the stages of eggs, larvae, pupae, and adults, the species must navigate and evade various threats such as predatory insects, birds, wasps, flies, parasitic wasps, as well as bacterial and fungal diseases. As a polygamous insect, female true armyworms release sex pheromones to attract and select multiple males as mates. The production and release of these pheromones are influenced by factors such as temperature, photoperiod (duration of light exposure), and juvenile hormones. Hearing plays a crucial role as a sensory mechanism for true armyworms, enabling them to engage in successful mating and avoid predation by bats (Westbrook et al., 2016).

Host plants

The caterpillars voraciously consume and inflict harm on various plants belonging to the Graminae family (weeds) as well as other crops. This includes a wide range of cultivated plants such as barley, corn, oats, wheat, rice, sorghum, alfalfa, beans, cabbage, cucumbers, onions, lettuce, and even the leaves of fruit-bearing plants (Zacarias, 2020).

Damage

Upon emerging from the ground, newly hatched larvae of armyworms emit silk threads and suspend themselves in the air. Utilizing the air currents, they travel from one plant to another. During their early developmental stages, they primarily consume the tender leaves located in the central whorl of the plant. As they mature, their feeding extends to older leaves, resulting in complete skeletonization. Adult caterpillars expel highly noticeable fecal particles. In cases of severe armyworm infestation, the entire leaf, including the central vein, may be consumed, giving the field the appearance of being grazed by livestock. These pests can also damage the ears of plants, including both husks and immature grains (Overton et al., 2021).

Eggs

Adult moths lay their eggs in clusters, typically consisting of 2 to 5 rows, on dry leaves and grass. These clusters are primarily positioned between the leaf sheath and blade. Female moths have the potential to deposit as many as 80 eggs per cluster, resulting in densely populated larvae groups. The total reproductive capacity of females ranges between 500 and 1500 eggs. The egg-laying phase typically lasts around 3.5 days in warmer conditions and approximately 6.5 days in cooler weather. Initially, the eggs appear white or yellowish, but as they near the hatching stage, they undergo a color transformation, turning gray in hue. A sticky substance present on the egg's surface enables it to adhere to adjacent foliage, aiding in camouflage and concealment (Wang, et al., 2022).

Larvae

The larval phase of armyworms comprises a minimum of six instars, although it can extend up to nine instars. During this stage, the caterpillar undergoes a size increase from 4 mm to 35 mm. In warm weather conditions, the larval stage typically lasts around 20 days, while in colder weather; it may extend to approximately 30 days. After hatching, the larvae begin feeding on the leaves of the plant they are positioned on. However, if the leaves become damaged, the larvae respond by releasing silk and dropping to the ground. During the later stages of development, the nocturnal larvae commonly seek refuge underground for protection during daylight hours. Typically, the larvae exhibit a gray-green or gray-brown coloration, with distinct longitudinal stripes running along the length of their bodies (Khawaja and Swati, 2021). Seitz characterized the larvae as having a coloration ranging from green to brown, with pronounced freckles. The streaks on their bodies are not easily distinguishable, and the dorsal line appears to fade within darker patterns. The dorsal line appears flatter, and its upper edge appears to disperse. Additionally, the sidelines and spiral lines exhibit a white coloration (Batallas et al., 2020).

Pupa

The process of pupation takes place underground within a protective silken casing constructed by the larvae. The pupa typically measures 13-17 mm in length and 5-6 mm in width. Notably, a pair of hooks protrudes from the abdomen. The duration of the pupal stage ranges from 7 to 14 days under warmer conditions and can extend up to 40 days in more favorable environmental conditions. Pupae primarily exhibit a yellowish-brown color, although there can be variations leading to a mahogany-brown hue (Madruga et al., 2019).

Adult

Adult true armyworms are primarily active during the nighttime, exhibiting nocturnal behavior. The entire life cycle, from egg to adult, spans duration of 30 to 50 days. In warmer conditions, the male adults have a life expectancy of approximately 9 days, while the females live for around 10 days. Under colder conditions, male adults have a longer life expectancy of about 19 days, whereas females live for approximately 17 days. The wingspan of an adult armyworm measures approximately 4 cm. The forewings have arranged black spots along the leading edge, giving them a distinctive pointed appearance. The forewings also feature a darker central area and numerous white spots. In contrast, the hind wings have a somewhat grayer coloration (Kawaja and Swati, 2021). The forewings exhibit an ochreous-gray coloration adorned with dark gray spots, often accompanied by indistinct reddish-brown markings. The round and kidney-shaped stigmata, which are pale yellow, contain a white dot positioned at the lower end of the latter. The outer rows of black spots on the veins are connected to the black stripes located at the upper portion of the wings. As for the hind wings, they display a maroon hue, with the base appearing lighter in color, while the veins remain black (Yusof et al., 2021).

Armyworm outbreak in Gilgit-Baltistan

In the initial days of May 2022, an abrupt epidemic of armyworm infestation was reported in GB specifically within the agricultural regions surrounding areas of Gilgit City including Jalalabad, Chamogarh, Jutal, Danyore, Juglote, and Basin. Promptly addressing the concerns, the Integrated Pest and Disease Management Unit of the Directorate of Agriculture Extension in Gilgit swiftly responded to the complaint. With a sense of urgency, the IPM Spray team promptly mobilized and deployed to the affected areas. Recognizing the severity of the situation, they initiated a comprehensive spray campaign to combat the rampant armyworm infestation. This campaign included the active involvement of local volunteers from the affected region. Through concerted efforts, the IPM team, in collaboration with the local volunteers, effectively managed to gain control over the dire circumstances caused by the destructive armyworm pest. The joint endeavor successfully mitigated the worst effects of the devastating attack. The integrated approach implemented by the IPM team, alongside the participation of local volunteers, exemplified the power of community-driven action and efficient pest management strategies. This event serves as a notable case study showcasing the significance of prompt response and collaborative efforts in effectively addressing and resolving agricultural pest outbreaks. The successful containment of the armyworm infestation provided respite to the farmers of Gilgit City and its peripheral areas. This incident stands as a testament to the efficacy of coordinated interventions in mitigating the harmful impact of pest outbreaks, ultimately safeguarding agricultural productivity and livelihoods.

Management of armyworm in GB

To combat this menace before reaching economic injury levels, the office of the Deputy Director, IPM Department of Agriculture Gilgit, took action on an emergency basis by formulating two spray teams in District Gilgit to handle this outbreak with the collaboration of local volunteers. At the same time, necessary inputs and equipment have been provided to the Deputy Directors of Agriculture offices of Diamer -Astore & Baltistan Region for launching the same campaign in their respective districts.

Distributions of pesticide traps and spray machines to different regions of Gilgit- Baltistan

The following tables show the district-wise details of inputs (pesticides & spray equipment) issued by the IPDM unit GB to control the armyworm in Gilgit-Baltistan (Table 1-6). IPDM unit GB has carried out chemical sprays in different regions of GB (Figure 1). Various crops have been widely infested by armyworms (Figure 2). Armyworm is severely infesting cereal crops (Figure 3). Presence or absence of armyworms in different locations in Gilgit-Baltistan has been shown in Table 7-10.

Table 1: The number of pesticides distributed in different districts of Gilgit region.

S. No.	Pesticides	Districts				
		Gilgit	Ghizer	Hunza	Nagar	Total (L)
1	Timer	00	50	100	40	76
2	Lamda	00	40	100	00	35
3	Neem Oil Triple Action	80	10	60	00	37.5
4	Bio Max (250ml)	10	00	60	00	8.5
	Total	120	100	320	40	160

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Table 2: The number of spray machines distributed in different districts of Gilgit region.

S. No	Spray Machines	Districts				
		Gilgit	Ghizer	Hunza	Nagar	Total
1	Power Spray Machines	01	03	00	00	04
2	Battery Spray Machines	07	08	22	00	15
	Total	08	11	00	00	19

Table 3: The number of pesticides distributed In different districts of Diamer region.

S. No.	Pesticides	Districts		
		Astore	Diamer	Total (L)
1	Timer (400ml)	40	104	144
2	Neem Oil Triple Action (250ml)	00	25	25
3	Lamda (250ml)	00	10	10
4	Biomax (250ml)	00	02	02
	Total	40	141	181

Table 4: The number of spray machines distributed in different districts of Gilgit Region.

S. No.	Spray Machines	Districts		
		Astore	Diamer	Total
1	Knapsack Battery Sprayer	08	10	18
2	Power Sprayer	02	02	04
	Total	10	12	22

Table 5: The number of pesticides distributed in the different districts of Baltistan region.

S. No.	Pesticide	Distiricts				
		Skardu	Khrmang	Shigar	Ghanche	Total (L)
1	Timer	40	50	100	40	230
2	Lamda	00	40	100	10	150
3	Neem Oil Triple Action	80	10	60	20	170
4	Bio Max	10	00	60	00	70
	Total	130	100	320	70	620

Table 6: Number of spray machines distributed in different districts of the Baltistan region.

S. No.	Spray Machines	Districts				
		Skardu	Kharmang	Shigar	Ghanche	Total
1	Spray Machine Power	03	03	03	03	12
2	Spray Machine Battery	12	10	10	12	44
	Total	15	13	13	15	56

Figure 1: Application of pesticides against armyworms in different districts of GB.

Figure 2: Armyworms infestations on various crops of GB.

Figure 3: Armyworms infestation on cereals (A-C).

Table 7: Presence or absence of armyworms in different locations of Gilgit.

REGION	Gilgit						
Locations	Crops, Cereals + vegetables					Fruit plants	
	Wheat	Beans	Alfalfa	Cabbage	Potato	Apricot	Walnut
Danyore	✓	✓	✓	✓	✓	✓	✓
Sultanabad	✓	✓	✓	✓	✓	✓	✓
Chamogarh	✓	✓	✓	✓	✓	✓	✓
Jalalabad	✓	✓	✓	✓	✓	✓	✓
Juglote	✓	✓	✓	✓	✓	✓	✓
Minawar	✓	✓	✓	✓	✓	✓	✓
Sakwar	✓	✓	✓	✓	✓	✓	✓
Nagaral	✓	✓	✓	✓	✓	✓	✓
Basin	✓	✓	✓	✓	✓	✓	✓

✓ Indicates presence; × Indicates absence

Preventions

Following measures have been suggested to prevent the spread of the insect pest

1. Utilize high-quality certified seeds that are specifically recommended for the given area. These seeds should possess desirable traits such as high germination rates, disease resistance, and increased yields (Gary, 2021).
2. Enhance plant health through appropriate plant spacing, soil management, and crop nutrition. This can be achieved through the application of organic or inorganic fertilizers, intercropping with nitrogen-fixing legumes, and implementing practices that promote vigorous plant growth. Robust plants are better equipped to withstand pest attacks and minimize damage (Nagoshi and Meagher, 2004).
3. Avoid late or staggered planting in plots of varying ages. Late-planted plots can attract a higher number of female moths, leading to concentrated egg-laying activities in those areas.
4. Increase plant diversity within plots. Certain plant species release chemicals that either repel or attract moths. Utilizing "push-pull" technology, where one plant species repels armyworms from maize while another species attracts them to areas where they can be easily controlled, can be an effective strategy.
5. Intercropping maize with non-grass species such as cowpea, beans, or pigeon pea also helps prevent infestation. Plant diversity can additionally enhance populations of

natural enemies, which contribute to the control of armyworm eggs and caterpillars (Westbrook et al., 2016).
6. Implement conservation agriculture practices that involve no-tillage, residue retention, crop rotation, and cover cropping. These practices have been found to increase the abundance and diversity of natural enemies such as spiders, beetles, and ants, while also improving soil health (Zacarias et al., 2020).

Table 8: Presence or absence of armyworms in different locations of Hunza-Nagar.

Locations	Crops, Cereals + vegetables					Fruit plants	
	Wheat	Beans	Alfalfa	Cabbage	Potato	Apricot	Walnut
Chalt	✓	✓	✓	✓	✓	✓	✓
Bodalus	✓	✓	✓	✓	✓	✓	✓
Chaprote	✓	✓	✓	✓	✓	✓	✓
Sikandarabad	✓	✓	✓	✓	✓	✓	✓
Minapin	✓	✓	✓	✓	✓	✓	✓
Badi nagir	✓	✓	✓	✓	✓	✓	✓
Jaffarabad	✓	✓	✓	✓	✓	✓	✓
Gahkuch	✓	✓	✓	✓	✓	✓	✓
Gohar abad	✓	✓	✓	✓	✓	✓	✓
Yasin	✓	✓	✓	✓	✓	✓	✓
Hyderabad	✓	✓	✓	✓	✓	✓	✓
karimabad	✓	✓	✓	✓	✓	✓	✓
Khuda abad	✓	✓	✓	✓	✓	✓	✓
Gojal	✓	✓	✓	✓	✓	✓	✓

Chemical control

1. While pesticides offer crop protection, it is important to recognize their limitations and potential risks. Pesticides can be expensive, pose health hazards to humans and livestock, and harm beneficial organisms in the environment, including natural enemies. Therefore, their use should be exercised with extreme caution (Overton et al., 2021).
2. Select nationally registered and labeled pesticides, giving preference to locally available options. Opt for pesticides that are specific in their target, rapidly degrade, and pose low health risks. It is crucial to avoid counterfeit and banned products. To prevent resistance development, rotate between pesticide groups with different modes of action (Wang et al., 2022).
3. Limit the number of pesticide sprays to a maximum of 2-3 applications per season.

CONCLUSION, DRAWBACKS, AND FUTURE PERSPECTIVES

In conclusion, this article has illuminated the timeline of the initial armyworm influx into Gilgit-Baltistan, which peaked from mid-April to June 2022. The invasion sequence began with cereals being the first crops to fall victim to the armyworms, followed by legumes, forages, and fruit trees. Rigorous field surveys and timely pesticide applications have been instrumental in addressing this challenge across all surveyed districts. These findings contribute to a deeper understanding of the armyworm migration patterns in GB, offering valuable insights for the development of effective pest management strategies. However, despite these advancements, there are noteworthy drawbacks that warrant attention. Morphological identification of various armyworm species presents limitations, underscoring the necessity for future adoption of molecular identification techniques to enhance accuracy and specificity. To fortify the region against future armyworm outbreaks, governmental initiatives must include comprehensive training programs for farmers, equipping them with the knowledge and tools needed to safeguard their crops from the onset of such pests. Looking ahead, the establishment of state-of-the-art laboratories focused on developing biopesticides and eco-friendly chemical alternatives emerges as a vital avenue. This proactive approach aims not only to manage armyworms sustainably but also to protect (Mukhtar et al., 2023; Rehman et al., 2023; Shahbaz et al., 2023) the environment and human health from the adverse effects of chemical pesticides. To foster resilience, the creation of dedicated plant breeding and genetics departments becomes essential, enabling the cultivation of crop genotypes resistant to armyworm infestations. The absence of a dedicated plant protection department in GB is a glaring gap that requires urgent attention. Establishing such an institute would be instrumental in effectively mitigating the impacts of future armyworm incursions and ensuring agricultural security. Furthermore, the imperative of raising farmer awareness about the intersection of climate change and armyworm proliferation cannot be understated. Collaborative efforts with stakeholders and farmers are pivotal to developing and refining armyworm risk assessment maps that adapt to changing climatic conditions. Lastly, a comprehensive research endeavor encompassing molecular identification of the fall armyworm is crucial to provide a scientifically grounded foundation for ongoing management strategies. By merging scientific rigor with practical application, a holistic approach to combating the armyworm menace can be realized, thereby safeguarding both agricultural productivity and environmental integrity.

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AUTHORS' CONTRIBUTIONS

ZH collected, arranged and analyzed the data and wrote the manuscript; IH supervised the work; AA proofread the paper; RA and MS provided technical assistance.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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