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Assessment of spatio-temporal dynamics of *Helicoverpa armigera* in chickpea, through ICT-based pest surveillance in Maharashtra

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Abstract

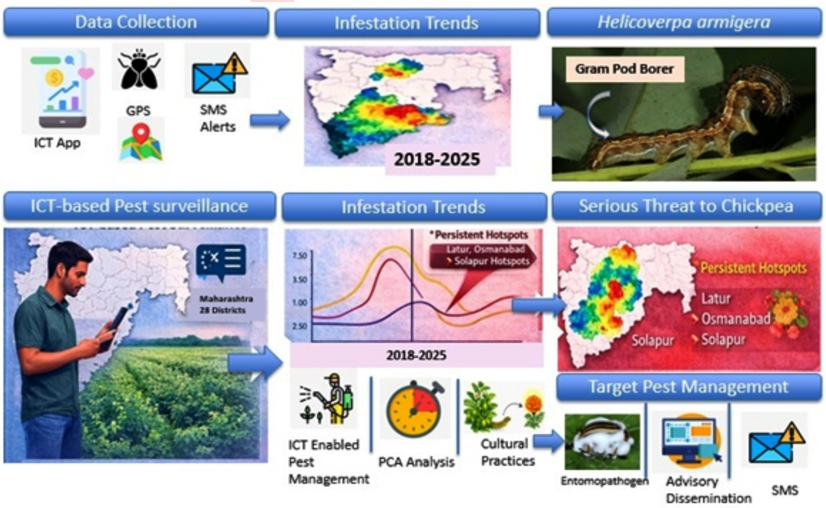
Aim: *Helicoverpa armigera*, the gram pod borer, poses a significant threat to chickpea production in India. This study aimed to understand the spatio-temporal infestation patterns of *H. armigera* using ICT-based surveillance across 28 districts in Maharashtra from 2018 to 2025, addressing how digital tools can support pest management decisions.

Methodology: Pest infestation data were collected through mobile-enabled scouting and analysed using Inverse Distance Weighted (IDW) interpolation and Principal Component Analysis (PCA). These tools help to identify spatial hotspots and temporal trends in pest outbreaks.

Results: A major outbreak was observed in 2019–20 with a peak relative abundance of 0.40 larvae m^{-1} row length followed by a steady decline to 0.04 larvae m^{-1} row length in later years (2022–2025). Persistent hotspots were found in Latur, Dharashiv and Solapur, whereas the northern and coastal districts showed minimal pest presence. PCA identified 2019–20, 2020–21, and 2024–25 as the years contributing most to pest variability.

Interpretation: This study highlights the effectiveness of ICT-based pest surveillance in supporting timely advisories and reducing pest infestation through targeted IPM interventions. These findings emphasize the need for district-specific monitoring and data-driven pest management strategies to ensure sustainable chickpea production in vulnerable areas of Maharashtra.

Key words: Chickpea, *H. armigera* , ICT, Management , Maharashtra, Pest surveillance



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Introduction

Chickpea (*Cicer arietinum*) commonly known as Bengal gram or gram and locally as 'Chana' is a pivotal pulse crop thatoccupies a vital position in India's agrarian economy. It is estimated that approximately 11.2 million ha land in India is under chickpea clutivation during 2023-2024, with a production of 11.9 million tonnes. In states like Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh, chickpea constitutes a major rabi crop that significantly contributes to both nutritional and income security. In 2023–24 rabi season, chickpea cultivation in Maharashtra was recorded as 713,000 tonnes in1.088 million hectares, making it the second most important pulse crop in the state as per the reports (Kumari & Malik, 2024). Despite its nutritional prominence and agronomic significance, chickpea productivity remains constrained due to recurring biotic pressures, particularly from insect pests and diseases that severely threaten yield and crop quality.

Among the insect pests, *H. armigera* (Hubner, Noctuidae, Lepidoptera), commonly referred to as the gram pod borer, is widely recognized as the most devastating pest of chickpea throughout the Indian subcontinent (Vikrant *et al.,* 2020) as it inflicts substantial damage by boring into pods and feeding on developing seeds leading to direct yield loss that can exceed upto 50% under severe infestations (El-Fakhouri *et al.,* 2022). *H. armigera* larval infestation not only affects the seed quantity, and quality, but also disrupts the physiological functioning of plant compounding economic losses to farmers. It has a wide host range, high fecundity, facultative diapause and resistance to conventional insecticides further exacerbate its management (Singh *et al.,* 2019). Traditionally, the management of *H. armigera* mainly rely on indiscriminate application of chemical pesticide. However, this strategy has led to pesticide resistance (Qayyum *et al.,* 2015), resurgence of non-target pests and adverse effect on environment and health impacts (Kashyap *et al.,* 2024).

Recognizing the unsustainable nature of sole chemical reliance, Integrated Pest Management (IPM) approaches have been extensively promoted as viable alternatives that which combines multiple pest control methods including biological, cultural, mechanical and judicious chemical use into a single framework aimed at reducing pest damage below economic threshold levels while minimizing ecological disruption (Zhou and Arcot *et al.,* 2024). Major IPM interventions against *H. armigera* in chickpea include the use of nuclear polyhedrosis virus (HaNPV) sprays (Parmar *et al.,* 2024), *Trichogramma chilonis* egg parasitoid releases, application of neem-based botanical extracts *i.e.,* NSKE @ 5% and the installation of pheromone traps for adult male monitoring and mass trapping (Pawar *et al.,* 2023; Wubneh *et al.*, 2016). Recent advances have highlighted the utility of trap crops such as marigold (*Tagetes* spp.) and sunflower (*Helianthus annuus*) in drawing *H. armigera* away from chickpea fields, thus reducing pod damage (Gyawali *et al.,* 2021). In parallel, the advent of digital tools and Information and Communication Technology (ICT) platforms has revolutionized the landscape of pest monitoring and management with real-time pest surveillance using mobile apps, GPS-enabled scouting tools and SMS-based alert systems that are increasingly being deployed to provide timely pest advisories to farmers at village level (Singh *et al.,* 2022). ICAR–National Research Institute for Integrated Pest Management (NRIIPM), in collaboration with the Commissionerate of Agriculture, Maharashtra has been implementing an ICT-enabled pest surveillance system across major chickpea-growing regions of Maharashtra using a mobile application interface, under "Crop Pest Surveillance and Advisory Project" (CROPSAP) (Singh *et al.,* 2022). The project, focus on spatio-temporal monitoring of *H. armigera* in major chickpea-growing belts of Maharashtra by integrating pest data, ETL-based color-coded risk indicators and targeted advisory dissemination through SMS. This initiative seeks to empower farmers with actionable pest management strategies to reduce the overuse of pesticides and safeguard chickpea yield and ecosystem health.

The present study not only makes an integrative effort to comprehensively understand the trends in shift of pest dynamics across the years in Maharashtra, but also elucidates the spatio-temporal abundance of *H. armigera* which aids in making timely decisions in pest management and also expands farmer's awareness of using non-chemical practices which will be a key factor in fostering sustainable chickpea production systems.

Materials and Methods

Study Area and Data Collection: In chickpea, pest dynamics of *H. armigera* were recorded through ICT based pest surveillance system, during rabi season from 2018 to 2025, across the major pulse-growing districts of Maharashtra state. In 28 districts of the state, regular pest surveillance and management advisories were disseminated to the farmers for assessing the pest situation in their fields (advisories Fig. 1). 5039 number of villages, each consisting of a minimum of 10 ha under chickpea cultivation, forming 305 talukas belonging to 28 districts were selected for pest surveillance. Two fixed and two random fields from each village were selected to monitor the activities of *H. armigera* activity (Vennila *et al*., 2016). The larval population was assessed daily by recording the number of larvae m^{-1} row length, replicated five times in randomly selected spots across the entire field (Vennila *et al*., 2016). The villages were categorized into groups, A and B for convenience of data collection, where in data was collected by agricultural assistants from Monday to Wednesday in Group A villages and from Thursday to Saturday in Group B villages. Thus, the pest data recorded was transferred into the centralized database.

The pest status of each fields was auto-analyzed based on ETL and visualized using colorcoded indicators that is orange (near ETL) and olive green (crossed ETL) (Singh *et al.,* 2022). Based on these ETLs, customized IPM advisories emphasizing integrated pest management strategies, at higher infestation levels, often recommended the application of bio pesticides, or ecologically safer chemical options were disseminated through

SMS in vernacular language, timed with crop phenology and pest stage. Pest surveillance summaries (number of larvae, damage) was aggregated into Standard Meteorological Week (SMW) formats for further analysis and advisory tracking, The complete details pertaining to the website and app are available at https://cropsap.maharastra.gov.in, wherein M CROPSAP is the mobile based data entry application that is utilized by the agriculture officers for data collection, based on which advisories are issued to registered farmers through SMS (Rawat *et al.,* 2017).

Data Processing and Mapping in R: Weekly pest data on *H. armigera* larval counts were visualized using the Inverse Distance Weighting (IDW) interpolation method after obtaining the corresponding geographic coordinates (Latitude, Longitude) of each location. Principal component analysis was conducted in R Studio (software 4.5.1) to assess the trend of *Helicoverpa* abundance in each district across the years.

Results and Discussion

The infestation trend analysis of *H. armigera* population in chickpea from 2018 to 2025 in Maharashtra was depicted in the form of relative abundance maps (Fig. 1), where in ETLs for *H. armigera* were delineated and typically, an ETL of 1–2 larvae / per row length or 5–10% pod damage was established as a critical threshold for initiating management measures in chickpea, which corroborates with the study of Hadiya *et al.* (2023). Similarly, the ETL for *H. armigera* was estimated to be one larva per meter row on gram crop (Singh, R., Taggar, G.K., 2021). This indicates that, based on the color of ETL obtained, management measures should be initiated at the field level. The abundance heat maps of *H. armigera* illustrate the spatio-temporal distribution of pest for different periods, amongst the districts of Maharashtra, the highest population (red) was recorded in Solapur, Dharashiv and Latur, followed by Aurangabad and Ahmednagar (yellow), for 2018-19 to 2024-25. *H. armigera* was widely distributed across central and western Maharashtra with moderate abundance (green) in regions like Pune, Nanded and parts of Washim and Hingoli whereas the Coastal areas, northern (Nandurbar, Dhule) and eastern districts (Gondiya, Bhandara, Chandrapur, Yavatmal) showed very low to negligible population during 2018-19. In 2019-20, the relative abundance dramatically increased to 0.40 (red) larvae m^{-1} row length, and the most intense hotspots were concentrated around Latur, Dharashiv and Solapur.

High to moderate abundance was observed across Aurangabad, Ahmednagar, Pune and Nanded. The coastal and eastern regions showed similar trend of low to negligible pest population like 2018-19. The key change was that this year marked a significant surge in the pest population, especially in the Latur- Dharashiv belt, with the highest peak abundance recorded across the years 2018-2025. During 2020-21, there was a sudden drop in population to 0.125 (red) larvae m^{-1} row length as compared to other years, wherein the maximum population was observed. The primary hotspot shift was slightly inclined to regions in and around Solapur, extending into Southern Dharashiv and Latur. Parts of Satara and Kolhapur also showed elevated (orange) abundance. Moderate abundance (light green) was recorded in areas *viz.,* Latur, Osmanabad, Ahmednagar, Aurangabad, Pune, Nashik, Dhule, Nanded, Hingoli, and Washim. Like the trend observed in previous years, the coastal belt, northern and eastern regions continued to show low abundance. A sharp reduction in the overall pest intensity indicated a less severe season all throughout, although the pest was widely distributed. A further drastic drop in the highest population counts *i.e.,* 0.10 larvae m^{-1} row length (red) row length was recorded during 2021-22 wherein the main hotspot was Solapur and Southern Dharashiv. Latur was similar to that of the previous year, but with reduced infestation. Moderate abundance (light green) remained widespread across Central Maharashtra including Pune, Ahmednagar, Aurangabad, Nanded, Hingoli and parts of Dhule. Persistent low abundance was observed in the coastal, northern, and eastern regions. Significant observational trend recorded during 2021-22 had continued reduction in peak abundance, suggesting a sustained decline in the severity of *H. armigera* outbreaks. A dramatic reduction in pest load was observed during 2022-23, indicating a relatively mild season for *H. armigera* as peak abundance dropped significantly to 0.04 larvae m^{-1} row length (red), and the hotspots were less intense, primarily around the Latur, Dharashiv and parts of Solapur and Nanded.

The distinction between hotspot and moderate abundance in 2022-23 became less pronounced due to the overall lower scale. The majority of affected area (Central Maharashtra) showed low to very low abundance (green to cyan). The areas of negligible abundance expand considerably encompassing more of the western, northern and eastern parts of the state. The peak abundance (0.04 larvae m^{-1} row length-red) recorded in 2023-24 was similar to 2022-23, which confirms that both years had same number of highest population count. The most affected areas like the previous year's,continue to be in Latur, Dharashiv, Solapur and Nanded, but at a very low intensity. The general area of pest persistence was recorded in the Central Maharashtra, however, the abundance levels were uniformly low (mostly green and cyan). Most parts of Maharashtra showed very low to negligible abundance, which indicated a combined trend of lower pest infestation was observed, suggesting a stable period of reduced *H. armigera* population. The highest population count of *H. armigera*, 0.04 larvae m^{-1} row length (red) was recorded during 2024-25, which was still consistent with the previous two years and hotspots were also recorded in the same core areas of Latur, Dharashiv, Solapur and Nanded that showed the highest abundance. Overall distribution pattern of lowest population count remained similar to 2022-23 and 2023-24. Many districts across the state experienced negligible or very low pest abundance, which proves the trend of consistently lower *H. armigera* relative abundance continuity extending into the year 2024-25, suggesting successful management strategies or unfavorable environmental conditions for pest sustenance.

Insect monitoring through pheromone traps play a crucial role in early detection and management of *H. armigera*. In corroboration with the present study, Manish Kumar *et al.* (2024) reported that pheromone traps installed in chickpea fields

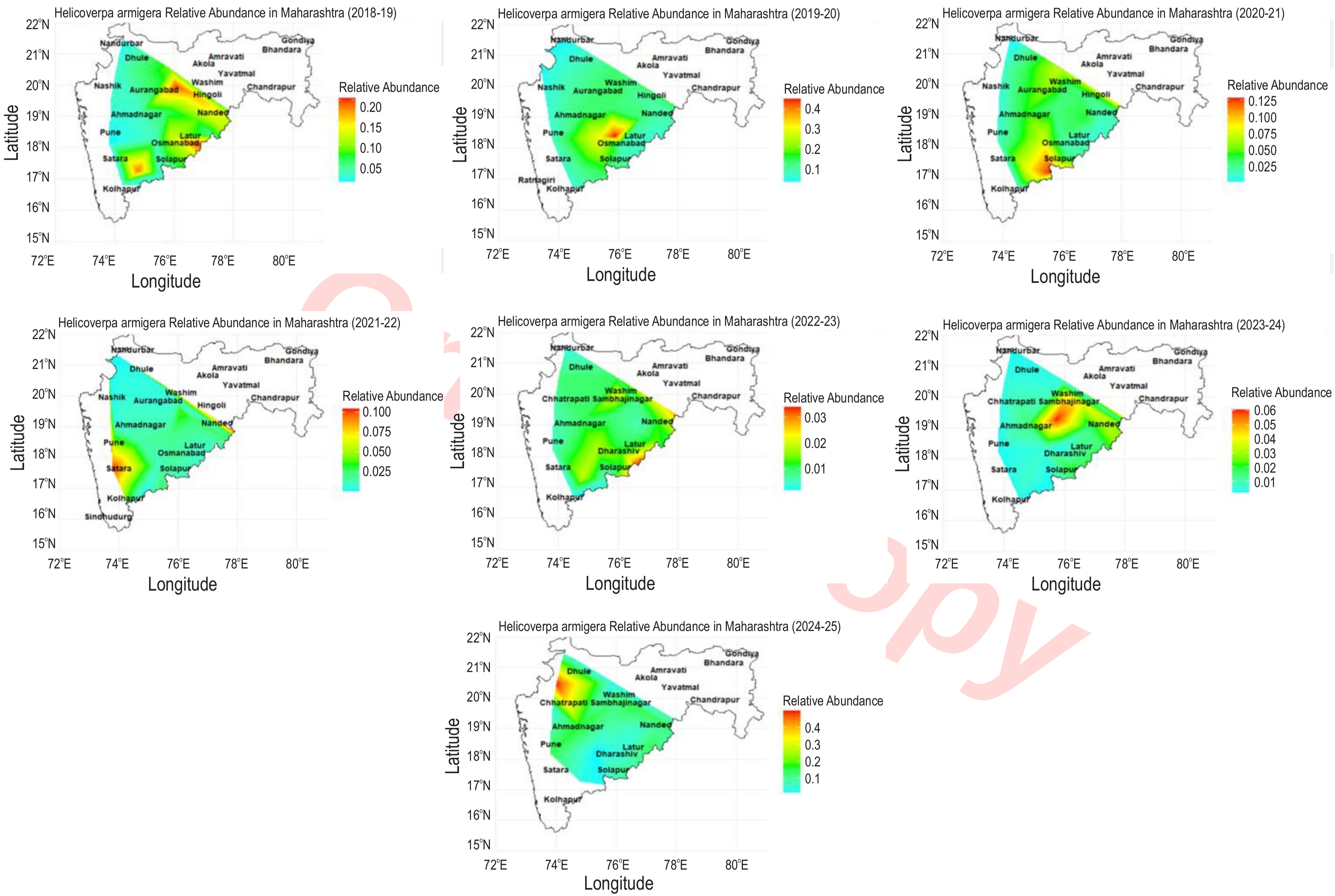

Fig. 1: Spatio-temporal distribution of *Helicoverpa armgiera* in Maharashtra from 2018-2025.

effectively monitored *H. armigera* population, with peak moth catches recorded during early March, coinciding with the crop's flowering and pod formation stage. The study reported that the highest moth catches occurred during 9th and 10th standard meteorological weeks (SMWs), corresponding to 28–30°C temperature. Trap density was found to reduce in larval infestation upto 35%.

Additionally, the traps provided a significant positive correlation (r=0.75) between moth numbers and maximum temperatures (27–31°C). The use of jowar as a natural bird perch and the removal of host weeds reduced the availability of alternate hosts, which directly impacts the *H. armigera* population is proved from the current study. Likewise, Kumar *et al.* (2015) reported that broadcasting 200 g of jowar per hectare at sowing attracted sparrows and other birds, which significantly reduced the bollworm infestations. This strategy reduced pod damage by approximately 32% in comparison to untreated plots. Weed removal such as Kolshi (*Tephrosia purpurea*), Ranbhendi (*Abelmoschus manihot*) and Petari (*Cajanus scarabaeoides*) reduced alternative food sources for the pest, contributing to a 20% decrease in the pest population. Biological control agents, including HaNPV (*Helicoverpa armigera* nucleopolyhedrovirus), *Beauveria bassiana* and *Bacillus thuringiensis* (Bt), provide sustainable pest control without harming the environment is confirmed from the present study. A similar study conducted by Tawidian *et al.* (2023) reported that application of *Beauveria bassiana* 1.15% W.P. @ 50 g 10 l^{-1} of water resulted in 68% reduction in larvae. The present study showed that chemical control using Spinosad and Indoxacarb is effective when pest population exceeds the economic threshold level (ETL). Meena *et al.* (2024) demonstrated that a spray of Spinosad 2.17% SC @ 3–5 ml 10 l^{-1} of water controlled *H. armigera* effectively, reducing larval infestation by 85%. Indoxacarb 15.80% EC, applied @ 5 ml 10 l^{-1}, resulted in a 78% reduction in larval number. Both insecticides also contributed to a significant increase in chickpea yield, with Spinosad leading to a 21% yield increase compared to untreated plots. Planting marigold as a trap crop around helps to control *H. armigera* population. Neem extract and Azadirachtin showed best results of population reduction due to anti-feedant and growth-regulating properties. Ahmad *et al.* (2015) found that a prophylactic spray of 5% neem extract or Azadirachtin at 0.30% WSP (300 ppm) applied at the vegetative stage of chickpea reduced *H. armigera* egg laying by 50% and reduced larval population by 60%. The study also highlighted that repeated applications at an interval of 15 days apart further reduced the damage by 40%, ensuring protection during critical growth stages. Handpicking of caterpillars during flowering and boll formation significantly reduces infestations as observed from the current study, which is in agreement with the reports of Kumar *et al.* (2015) who showed that manual removal of *H. armigera* larvae during flowering and boll formation stages resulted in a 28% reduction in pod damage.

The annual demographic comparison of historical data showed that in 2018-19 the peak was 0.20 larvae m^{-1} row length, followed by a significant increase of major outbreak in 2019-20 with 0.40 larvae m^{-1} row length, after which a decline in trend of pest population was recorded in 2020-21 (0.125), which further decreased to 0.100 larvae m^{-1} row length during 2021-22 and a still further dramatic decrease of overall abundance was observed in 2022-23 (0.04), which sustained during the years 2023-24 and 2024-25. This confirmed that the Solapur, Latur and Dharashiv districts were the main hotspots during 2018-2025

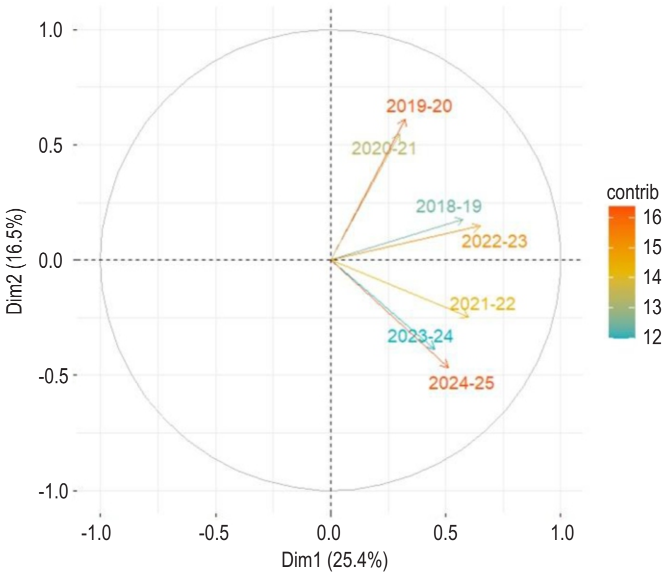

Fig. 2: Principle component analysis of *H. armigera* infestation in Maharashtra from 2018 to 2025

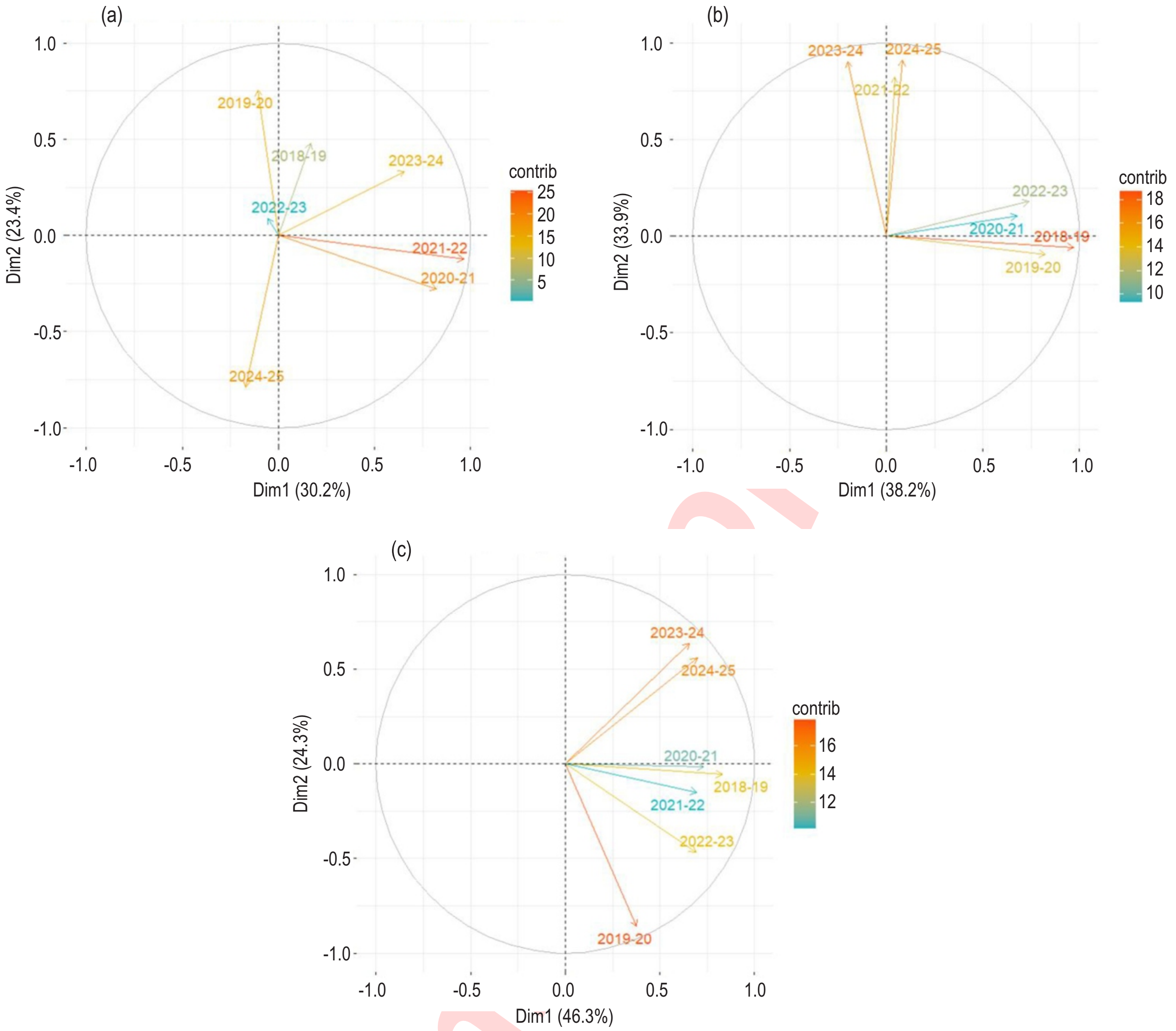

Fig. 3: Trend of *H. armigera* Infestation in districts (a) Solapur; (b) Latur and (c) Dharashiv identified as hotspots from 2018 to 2025.

whereas the lowest populations were observed in the west of the Western Ghats, northern and eastern districts of Maharashtra consistently from 2018-2025, showing a very low to negligible *H. armigera* relative abundance across all the years. This suggests these regions were consistently less favorable for the pest's proliferation, likely due to timely management practices, the influence of weather factors or predominant cropping patterns (Meena *et al.*, 2025).

The maps depict that Maharashtra experienced a severe outbreak of *H. armigera* population in 2019-20, thereafter witnessed a positive trend of significant reduction in the pest's relative abundance, last three years 2022-23, 2023-24 and 2024-25 showed consistently a low pest load across the state. This trend is highly beneficial for agriculture in Maharashtra, potentially leading to reduced crop losses. PCA plot aggregates *H. armigera* infestation data across the entire state of Maharashtra. Dim1 explains 25.4% of the variance, and Dim2 explained 16.5%, together accounting for 41.9% of the total variability. The statewide results revealed overall trends in pest infestation (Fig. 2). The relatively moderate percentage of variance explained by the first two dimensions suggest that *H. armigera* infestation in Maharashtra is influenced by multiple complex factors that vary across the years and perhaps regions. The proximity of 2019-20 and 2020-21 indicates similar pest patterns, while 2024-25 was distinctly different, highlighting significant year-to-year variation in pest dynamics at state level. Years with high contribution are those where pest infestation patterns were most influential in defining the overall statewide variability. The graph (Fig. 2) represents the results of a Principal Component Analysis (PCA) indicating that they capture a

Table 1: List of advisories sent within districts of Maharashtra based on ETL level

Pest	Brief Advisory
Cultural, Physical, Mechanical control advisories sent to different districts of Maharashtra (LOWER OR NEAR ETL)	1. At the time of sowing, broadcast 200 grams of jowar(Sorghum) per hectare in the field so that it serves well as a natural bird perch. 2. Remove and destroy weeds like Kolshi (*Tephrosia purpurea*), Ranbhendi (*Abelmoschus manihot*) and Petari (*Cajanus scarabaeoides*) from bunds. 3. Plant a row of marigold as a trap crop around the main crop. 4. Install 'T' shaped bird perches 1 to 1.5 feet taller than the crop at intervals of 15-20 meters (50 per hectare). Sparrows, mynas, common crow 5. etc., will sit on these perches and pick and eat bollworms. 6. Install 5 pheromone traps per hectare at 1 meter height from the ground for monitoring moths. 7. When the crop is in its initial vegetative growth phase, a first prophylactic spray of 5% neem extract or *Azadirachtin* 0.30% WSP (300 PPM, 50 ml per 10 liters of water) and a second spray 15 days later will prevent moths from laying eggs on such crops. 8. When the crop is at 50% flowering and during early boll formation, if the infestation of caterpillars increases, handpick as many caterpillars as possible and immerse them in kerosene-mixed water to kill them. 9. Biological agents are highly effective for the efficient management of bollworms. As soon as the first and second instar caterpillars are observed, spray with HaNPV virus at 250 L. E. (10 ml per 10 liters of water). To enhance the effectiveness of the virus and protect it from sunlight, mix 1 gram of Ranipal (dye) in the spray solution. Alternatively, spray with the pathogenic fungi *Beauveria bassiana* 1.15% W. P. (50 grams) or *Bacillus thuringiensis kurstaki* 0.5% W. P. (40 grams) per 10 liters of water.
Chemical advisories sent to different districts of Maharashtra (ABOVE ETL)	For the management of *H. armigera*: Spray Spinosad 2.17% SC @ 3-5 ml/10 lit or Indoxacarb 15.80% EC @ 5.0 ml/10 lit of water.

significant portion of the underlying patterns, although other factors or dimensions also contribute to the overall variance of the population. The positions of the years (represented by arrows) illustrate their relative similarities and differences in pest infestation patterns as observed in 2019-20 and 2020-21 which were relatively close, suggesting similar infestation profiles during these periods. In contrast, 2024-25 was distinctly separated from other years, particularly from 2018-19 and the cluster around 2021-22 and 2022-23, indicating unique or highly contrasting pest dynamics in that year. The 'contrib' color scale highlights the contribution of each year to these principal components; years like 2019-20, 2020-21, and 2024-25 show higher contributions, indicating that their infestation patterns were particularly influential in defining the overall observed variability across the state.

PCA plots for individual districts of Maharashtra provide a more localized view of *H. armigera* infestation patterns for specific districts within Maharashtra. As the hotspots were detected mostly as Solapur, Latur and Dharashiv districts among all the years (2018-2025), the PCA trend of the years amongst these districts were compared (Fig. 3), which illustrate that Solapur, distinct shifts in contribution to variability were observed in 2019–20, 2021–22 and 2024–25 suggesting notable fluctuations in pest pressure during these years. Latur showed a strong divergence particularly in 2023–24 and 2024–25 with a cluster of early years (2018–21) contributing less to the variation, indicating more recent years had increased pest activity. In Dharashiv, the years 2019–20, 2023–24, and 2024–25 exhibited greater influence on the PCA axes, pointing to rising *H. armigera* infestation during that period. This detailed understanding of district-specific pest dynamics crucial for developing and implementing targeted, efficient and locally adapted Integrated Pest Management strategies enabling more precise interventions and resource allocation to effectively manage *H. armigera* and promote sustainable production of chickpea in Maharashtra.

The current study provides critical insights into the temporal fluctuation and spatial distribution of *H. armigera* populations across Maharashtra from 2018 to 2025. Severe infestation observed in 2019–20, followed by a significant and sustained decline, aligns with regional trends of pest resurgence followed by stabilization, as reported in Central Maharashtra (Wu *et al.,* 2020) These patterns are often influenced by pest resistance dynamics, weather anomalies and landscape level ecological factors. The spatial concentration of high pest pressure in Latur, Dharashiv and Solapur corroborates the concept of "pest persistence zones" highlighted by Specht *et al.* (2021), who emphasized that *H. armigera* tends to persist in intensively cropped, warm and dry landscapes with reduced natural enemy pressure. Identification of consistent low-abundance regions such as Nandurbar and Gondiya, in this study is further supported with the findings of Jones *et al.* (2019), who reported that pest development is limited in high-humidity, low-temperature regions due to prolonged larval development time. The efficiency of ICT-based pest surveillance is evident from the post 2020 pest decline. Similar successes were observed by Ward *et al.* (2020) in Ethiopia, where digital surveillance helped manage Fall armyworm outbreaks. In India, Mahapatra *et al.* (2021)

demonstrated that real-time pest alerts through mobile-based tools increased farmer responsiveness and reduced chemical misuse, aligning with the decreasing abundance trend observed in this study after targeted advisories. Moreover, the successful implementation of IPM practices (Table 1) from the present study has proven to be effective in lowering *H. armigera* population (Kumar *et al.,* 2020). The findings of this study reflect that IPM strategies contributed to the sustained suppression of pest infestation in Maharashtra. Wang *et al.* (2021) emphasized that even minor shifts in rainfall and temperature during pod development stages can disrupt *H. armigera* life cycles, which explains the declining population in 2022–2025, where weather data may have interacted synergistically with IPM efforts to reduce pest survival. Principal Component Analysis (PCA) revealed that years like 2019–20 and 2024–25 were outliers, indicating distinct pest behavior. This observation supports the findings of Guedes *et al.* (2016), who demonstrated that pest behavior in agro-ecosystems is highly nonlinear and influenced by multiple biotic and abiotic factors. Ultimately, the results confirm the dynamic, multi-scalar nature of *H. armigerai* nfestation. The continued effectiveness of localized pest surveillance, adaptive IPM and ICT-based tools underscores their critical role in sustainable pest management as emphasized by Machekano *et al.* (2017) in their global review of lepidopteran pest management.

PCA highlights that *H. armigera* outbreaks in Maharashtra are highly dynamic, with 2019–20, 2020–21, and 2024–25 driving major variability. These fluctuations reflect the influence of environmental conditions and management practices. Such insights are practically valuable for building predictive pest-forecasting models and refining integrated pest management strategies, enabling timely interventions and reducing crop losses.

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