

Original Article

Effect of Climate Change on Pest Population: A Review

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Abstract:

Global agroecosystems are undergoing measurable disruption as rising temperatures, elevated atmospheric CO₂, and shifting precipitation patterns reshape the ecology of insect pests. Warming accelerates pest metabolism and development, shortens generation time, improves overwintering survival, and expands geographic ranges poleward and to higher elevations, while altering the synchrony between pests, their host plants, and natural enemies. Documented cases include the poleward range shift of the brown planthopper, the northward expansion of pesticide-resistant diamondback moth populations, and the continuing spread of fall armyworm across new continents. Current estimates place climate-driven insect damage at 10–25% of crop losses in major cereal-growing regions, with projections of yield reductions as high as 50% by 2050 under unmitigated warming.

Keywords: *Climate Change, Insect Pests, Range Shift, Voltinism, Integrated Pest Management, Food Security.*

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Introduction:

Rising global temperatures, elevated atmospheric carbon dioxide concentrations, and increasingly erratic precipitation are altering the physiological, ecological, and evolutionary trajectories of insect pest

populations worldwide. Climate parameters exert direct effects on agricultural insect pests by expanding their geographic distribution, increasing overwintering survival, raising the number of generations completed per year, altering synchrony between plants and pests,

modifying interspecific interactions, and increasing the risk of invasion by migratory species, while simultaneously reducing the effectiveness of natural biological control (Skendžić *et al.*, 2021). These combined pressures translate into a serious and growing risk of crop and economic loss, alongside a mounting challenge to global food security.

A recent synthesis concluded that the evolution of climate change is significantly transforming agroecosystems worldwide, leading to unprecedented shifts in crop pest

populations that threaten global food security by intensifying pest pressure through physiological, ecological, and evolutionary pathways (Hussain *et al.*, 2025). The same review reported that warming has already driven a 10–25% increase in crop losses attributable to insects across major breadbasket regions, with the potential to reduce yields by as much as 50% by 2050 if current warming trends persist (Hussain *et al.*, 2025).



Mechanisms Linking Climate Change to Pest Population Dynamics:

Accelerated Development and Increased Voltinism:

Insects are ectotherms whose developmental rate, metabolism, and reproductive output are tightly coupled to ambient temperature. As regional temperatures rise, pest species frequently complete more generations per growing season, a phenomenon known as increased voltinism. Modelling of fall armyworm (*Spodoptera frugiperda*) broods under

projected climatic scenarios found that while three to four generations are currently the most common in the studied region, four to five generations become possible under warming, with as many as seven generations occurring in some areas by later in the century, a marked increase from the six generations currently achievable only in small pockets (Montezano *et al.*, 2024). More days with favourable warm temperatures during a breeding season shorten the pest's life cycle and thereby enable additional broods per

season, directly compounding pressure on host crops.

Range Expansion and Overwintering Survival:

Warmer winters allow pest populations to survive and establish in regions previously too cold for persistence, driving poleward and altitudinal range expansion. A 2024 *Scientific Report* study modelling the brown planthopper (*Nilaparvata lugens*), a major long-distance migratory rice pest, projected that its overwintering boundary would expand poleward under both moderate and high-emission climate scenarios, with new overwintering areas emerging in the mid-latitude regions of central-to-eastern China and mid-to-southern Australia (Hong *et al.*, 2024). Notably, the same modelling work found that while habitable areas for the pest remained broadly similar in extent, habitat suitability decreased substantially in near-equatorial regions owing to increasing heat stress, with marginal-suitability areas rising from 27.2% to 38.8% and highly favourable areas collapsing from 27.5% to just 3.6% under the most extreme emissions pathway (Hong *et al.*, 2024).

A parallel dynamic has been documented for the diamondback moth (*Plutella xylostella*), a globally significant pest of brassica crops. Using experimentally parameterised and field-tested models,

researchers demonstrated that climate change over the past fifty years increased the moth's overwintering range by approximately 2.4 million square kilometres worldwide, a shift that has troubling secondary consequences: the expanded range coincides with regions of intensifying pesticide selection pressure, promoting the spread of pesticide resistance alongside the pest itself (Fu *et al.*, 2021).

Phenological Mismatch and Altered Ecological Interactions:

Beyond simple range and generation-count effects, climate change can desynchronise the timing of pest emergence from that of host-plant phenology and natural enemy activity. Further changes in climate conditions could alter the synchrony between plant and insect phenology, thereby altering the vulnerability of host plants, and could also disrupt the enemy–herbivore dynamic by impairing the ability of parasitoids to regulate their pest hosts (Régnière *et al.*, 2024). Such disruptions are of particular concern in forest pest systems: a continental-scale analysis of the spruce budworm across North America found that recent climate change had already produced measurable shifts in insect phenology, reproduction rate, winter survival, and potential population growth rate over a 73-year historical record, contributing to a documented northward shift in outbreak range (Régnière *et al.*, 2024).

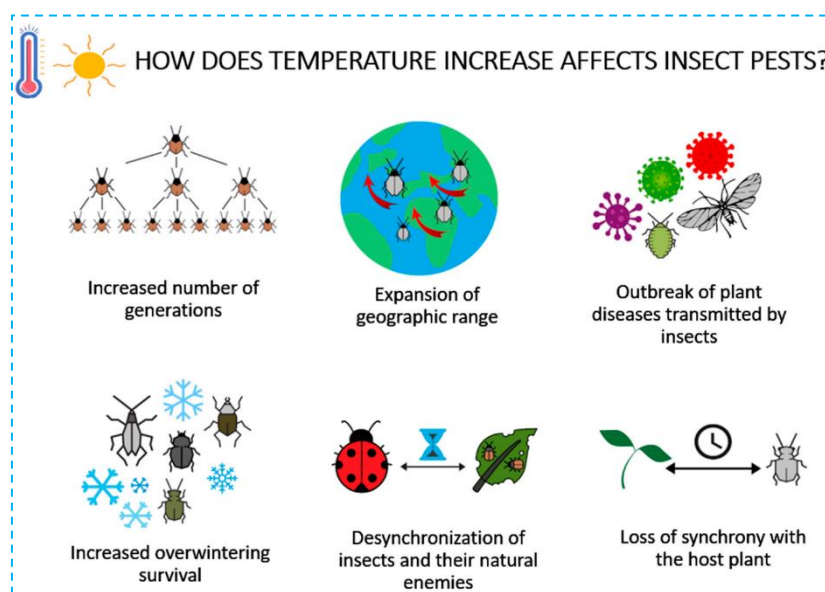
Table 1. Representative Climate-Driven Effects on Insect Pest Populations

Pest species	Climate driver	Documented / projected effect	Source
Brown planthopper (<i>Nilaparvata lugens</i>)	Warming, shifting overwintering boundary	Poleward expansion of overwintering range into mid-latitude China and Australia; sharp loss of near-equatorial habitat suitability	Hong <i>et al.</i> (2024)
Diamondback moth (<i>Plutella xylostella</i>)	50-year warming trend	Overwintering range expanded by ~2.4 million km ² ; co-occurring spread of pesticide resistance	Fu <i>et al.</i> (2021)
Fall armyworm (<i>Spodoptera frugiperda</i>)	Warmer breeding-season temperatures	Increase from 3–4 to potentially 6–7 generations per season in parts of its range	Montezano <i>et al.</i> (2024)
Spruce budworm (forest pest)	73-year regional warming (1950–2022)	Shifts in phenology, reproduction, winter survival, and outbreak range (northward)	Régnière <i>et al.</i> (2024)
Aggregate cereal/maize systems	General warming trend	10–25% current increase in insect-driven crop losses; up to 50% projected yield loss by 2050	Hussain <i>et al.</i> (2025)

Case Study: Fall Armyworm as a Bellwether of Climate-Driven Pest Spread:

Since its first African outbreak in 2016, fall armyworm has become emblematic of climate-linked pest invasion. The pest can cause substantial yield losses of up to 80–100% in maize fields, affecting all growth stages from seedling to cob-setting, and its spread across Africa has resulted in maize losses ranging from 8.3 to 20.6 million tonnes across the twelve major maize-producing countries on the continent (Tambo *et al.*, 2024). Modelling of its potential distribution in newly invaded regions such as India, using CMIP6 climate projections under contrasting emissions pathways, found that roughly 40.5% of Indian territory is already climatically suitable for the pest under current conditions,

with high suitability concentrated in southern and eastern states and further expansion anticipated as warming continues (Kumar *et al.*, 2025). Farmer-level surveys corroborate these modelled trends: in a survey of smallholder maize growers in central Ethiopia, 83% of respondents reported an increase in the severity of fall armyworm damage, which they linked to changes in rainfall amount and distribution following planting, with an estimated average maize yield reduction of 22.2% attributable to the pest (Bedasa & Degaga, 2025). These converging lines of evidence, spanning mechanistic climate models and grassroots farmer observation, illustrate how climate-driven pest pressure is already a lived agricultural reality rather than a distant projection.



Implications for Pest Management:

The intensification and spread of pest populations under climate change carries direct consequences for the tools used to manage them. The four common pest control tactics, chemical insecticides, pheromone-based mating disruption, entomopathogens, and biological control by entomophagous arthropods, concluded that insecticide use is likely to increase because of higher pest populations, although the effect of temperature on insecticide toxicity is complex and varies between compounds and species (Perrin *et al.*, 2025). Later it was found that entomopathogens may see improved efficacy under warming, since higher temperatures can enhance their infectivity, whereas the outcome for biological control using natural predators and parasitoids is highly context-dependent, hinging on the relative thermal sensitivity of pests and their natural enemies (Perrin *et al.*, 2025). This asymmetry underscores a central management challenge: climate change does not uniformly favour or disadvantage any single control tactic, requiring locally

calibrated, adaptive strategies rather than one-size-fits-all responses.

Future Thrust:

Several priorities emerge for strengthening the resilience of pest management systems under continued climatic change:

1. **Climate-smart integrated pest management (IPM).** Management frameworks should be adapted to reflect projected shifts in voltinism, range, and overwintering survival, moving away from static regional thresholds toward dynamically updated, climate-informed action thresholds.
2. **Phenology-based surveillance networks.** Given the risk of phenological mismatch between pests, host crops, and natural enemies, expanded monitoring systems that track real-time developmental stages rather than fixed calendar dates would improve the timing and precision of interventions.

3. **International coordination on migratory and invasive pests.** Species such as the brown planthopper and fall armyworm cross national boundaries as their climatic envelopes shift; the modelling literature explicitly calls for international monitoring programmes to manage these emerging cross-border risks effectively.
4. **Resistance-aware pesticide stewardship.** Because pest range expansion has been shown to co-occur with the spread of pesticide resistance, resistance monitoring should be integrated into range-expansion forecasting rather than treated as a separate concern.
5. **Ecological modelling and genomic innovation.** Combining species distribution modelling with genomic tools, including CRISPR-engineered crop resistance, offers a route toward pest control strategies that anticipate rather than merely react to climatic shifts.
6. **Farmer-inclusive adaptation.** Grassroots evidence indicates farmers already perceive climate-linked increases in pest severity; incorporating their observational data into formal monitoring and involving them directly in adaptation planning can improve both the accuracy and the local relevance of climate-pest forecasting.

Conclusion:

The accumulating evidence base leaves little doubt that climate change is actively reshaping the population dynamics of agricultural and forest insect pests, through

accelerated development, increased voltinism, expanded and shifting geographic ranges, improved overwintering survival, and disrupted phenological synchrony with host plants and natural enemies. Case studies spanning the brown planthopper, diamondback moth, fall armyworm, and spruce budworm demonstrate that these shifts are already measurable across multiple continents and cropping systems, with real economic consequences for smallholder and industrial agriculture alike. Because the effectiveness of individual pest control tactics responds unevenly to warming, resilient pest management will depend on integrated, regionally calibrated, and continuously updated strategies rather than static protocols. Continued investment in predictive modelling, cross-border surveillance, and farmer-inclusive adaptation will be essential to safeguarding global food security as the climate continues to change.

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