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Bio-Ecology of Maize Spotted Stem Borer, *Chilo partellus* (Swinhoe) and Biorational Approaches for Sustainable Management

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Abstract: The maize spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) is a key pest causing 25–80 per cent yield losses in maize across Asia and Africa. Its wide host range, rapid development and climatic adaptability make management challenging. This review summarizes current understanding of its bio-ecology and sustainable biorational control options. Microbial agents like *Bacillus thuringiensis*, *Beauveria bassiana* and *Metarhizium anisopliae* provide effective larval suppression and yield improvement. Insect growth regulators, pheromone-based mass trapping and recent tools including RNA interference and nanobiopesticides further strengthen eco-friendly management. Integrating these interventions within maize IPM modules reduces pest incidence besides conserving beneficial fauna. Continued progress in host resistance, formulation technologies and predictive decision-support tools will enhance long-term resilience. Collectively, the reviewed evidence highlights the potential of biorational-based IPM as a sustainable alternative to conventional insecticides for managing *C. partellus* in maize.

Keywords: Biorational management, Biopesticides, *Chilo partellus*, RNAi, Semiochemicals

Chilo partellus (Swinhoe) remains a major stem borer of maize (*Zea mays* L.) across tropical and subtropical Asia and Africa despite decades of management efforts (Panwar 2005). Originally documented from the Indian subcontinent (Kfir et al., 2002) and taxonomy is now well resolved, with molecular assessments placing it within a diverse genus (Regier et al., 2012) comprising numerous species distributed globally. Although the recent invasion of *Spodoptera frugiperda* (J.E. Smith) has shifted maize crop pest dynamics in many regions, *C. partellus* continues to inflict substantial whorl and stem damage, particularly under rainfed, late-sown, and climate-stressed production systems (Hailu et al., 2021). Dual infestations of *C. partellus* and *S. frugiperda* are increasingly reported in South Asia, with the former dominating early crop stages and in dry, low- to mid-altitude ecologies where warming trends favour its development (Mutamiswa et al., 2022, Mir et al., 2022). These patterns affirm its continued relevance as a key pest, warranting sustained surveillance, research and integrated management attention.

Distribution, spread and phytosanitary risk: *Chilo partellus* is considered to have originated in the India-Pakistan region but has since established across major maize-growing regions of Africa and Asia. It is widely reported throughout eastern, central and southern Africa, including Kenya, Uganda, Ethiopia, Tanzania, Zambia, Zimbabwe and South Africa and is similarly widespread in Asian countries such as Afghanistan, Bangladesh, India, Nepal, Pakistan and Sri Lanka (Jalali and Singh 2003, EPPO 2014). Within India, its presence across nearly all maize-growing states reflects broad ecological adaptability. Although traditionally dominant in low- and mid-altitudes (<1500 m), recent field observations and modelling studies indicate ecological range expansion into temperate and highland zones, supported by phenotypic plasticity and thermal tolerance (Mutamiswa et al., 2022). Establishment in the temperate Kashmir valley further demonstrates adaptation to cooler climates (Mir et al., 2022). Recent detection in southeastern Türkiye confirms its spread into the Mediterranean basin (Tonga 2023), emphasizing its invasive potential.

From a regulatory standpoint, *C. partellus* is listed by EPPO (code “CHILZO”) and recognized within the CABI Crop Protection Compendium as a high-impact stem borer. Several sub-Saharan African countries classify it as a quarantine concern under the International Plant Protection Convention (IPPC) and national Plant Protection Acts.

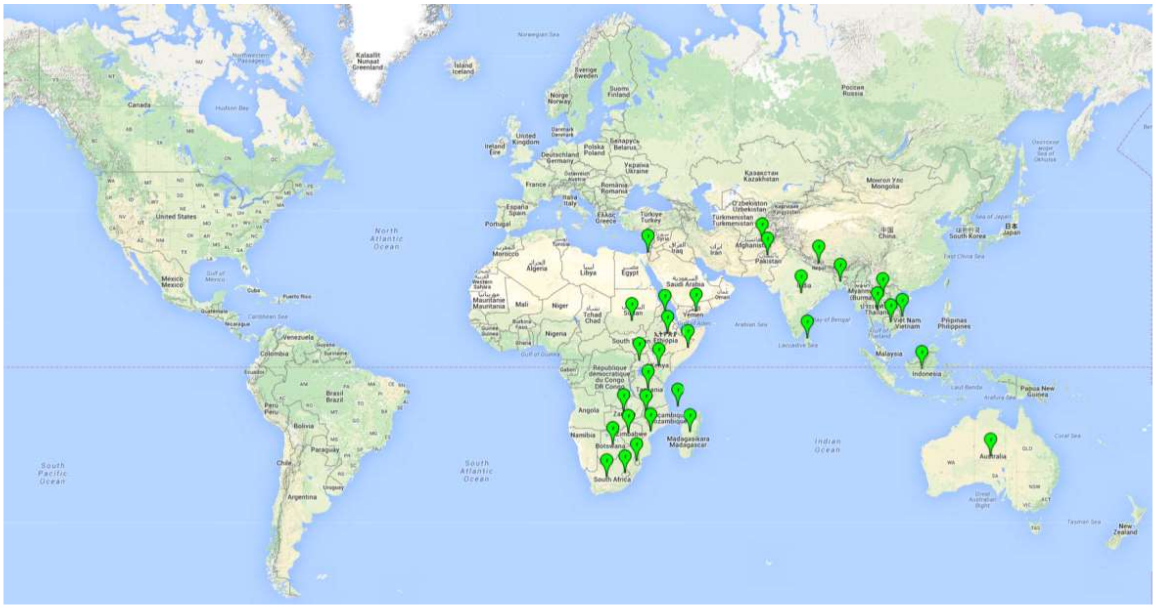
Life history and biology: *Chilo partellus* exhibits high fecundity, rapid development and strong ecological adaptability, traits that sustain its prominence in maize production systems. Adults are crepuscular, mate shortly after emergence and oviposit over several nights, placing egg batches along the leaf midrib during the whorl stage. Females typically lay several hundred eggs, influenced by host genotype and environmental conditions (Bhoi et al., 2020). Adult longevity averages 5-6 days, with premating, mating and oviposition periods well described (Siddalingappa et al., 2010). Egg incubation ranges from 4-10 days depending on temperature. Larvae initially feed in the whorl before boring into the stem and complete development through six instars, with instar durations and total larval periods (20-51 days) detailed by Siddalingappa et al. (2010). Thermal constant estimates (~580-600 degree-days) support 5-7 generations per year in tropical regions (Tamiru et al., 2012). A facultative larval diapause occurs at high elevations or during dry seasons, whereas populations in warm lowlands develop continuously (Ong'amo et al., 2016). Recent physiological studies highlight metabolic adjustments under cold stress, indicating diapause-linked plasticity (Sau et al., 2023).

Mortality factors and life table studies: Life-table studies on *C. partellus* consistently show that early larval stages experience the highest mortality due to predation, parasitism, disappearance losses and abiotic stress ((Jalali et al., 2003, Midega et al., 2005). Seasonal dynamics reveal positive population growth during warmer kharif periods, with declines toward rabi, highlighting strong climatic regulation. Host-based life tables emphasise the role of maize cultivar and environmental stress in shaping larval survival and generational survivorship, with marked reductions across successive generations (Suneel Kumar and Madhumati 2018). Key-factor analyses identify larval disappearance and parasitism, particularly by *Cotesia flavipes*, as major contributors to density-dependent regulation (Suneel Kumar and Madhumati 2018).

Recent studies highlight the increasing influence of climate variability on mortality patterns. Elevated temperatures and low humidity reduce larval survival and suppress adult emergence (Mutamiswa et al., 2022). Temperature-dependent host-parasitoid interactions show reduced parasitoid efficiency at extreme temperatures (Mutamiswa and Nyamukondiwa 2020). Thermal-based demographic modelling indicates that the intrinsic rate of increase (r_m) peaks near 30 °C but declines beyond upper thermal limits (Khadi et al., 2023). Together, these findings show that while biological control remains vital, heat and moisture fluctuations are emerging as dominant mortality drivers under changing climates.

Extent of yield losses due to stem borer, C. *partellus* in maize: Yield losses caused by *C. partellus* vary widely across agro-ecologies, hybrids and seasons, depending on crop stage, infestation intensity and environmental stress (Vinay Kumar 2024). Larval attack during 10-20 days after emergence results in the greatest losses due to dead-heart formation, reduced photosynthesis and stunting. Field studies report yield reductions typically ranging from 22-48%, with higher losses under late sowing, moisture stress or warmer environments (Kumar et al., 2021). Protected-unprotected trials in India further demonstrate substantial reductions (70.0 to 31.55 q/ha), reaffirming the significance of early-season damage (Suneel Kumar et al., 2017b). Economic injury level studies indicate that infestations exceeding 2-3 larvae per plant produce statistically significant yield penalties (Suneel Kumar et al., 2017a).

Climate-responsive analyses suggest heightened risks under warming and extended dry spells, with modelling predicting increased developmental suitability and higher yield losses in transitional and mid-altitude zones (Mutamiswa et al., 2022, Khadi et al., 2023). Field



Source: Ong'amo et al. (2016), reproduced from Pest Distribution and Risk Atlas for Africa (CIP, Peru)

Fig. 1. Global distribution of *C. partellus* (Green points indicate countries with confirmed pest establishment)

assessments also report 25-42% losses under late-sown or water-stressed conditions (Mir et al., 2022). Overall, yield losses may vary from 25-80% depending on hybrid susceptibility, sowing window, infestation pressure and local climatic variability.

Bio-efficacy of biorationals for *C. partellus* management in maize: Growing concerns over pesticide residues, environmental impact and declining efficacy of conventional insecticides have strengthened the focus on biorational alternatives for sustainable *C. partellus* management in maize.

Botanical insecticides: Neem- and karanj-based botanicals continue to serve as core components of stem borer management owing to their ovicidal, antifeedant and growth-regulatory effects (Isman 2020). Classical studies demonstrated that neem oils, seed kernel extracts (NSKE) and azadirachtin formulations effectively deter larval feeding and reduce dead-heart incidence in maize (Jalali and Singh 2004, Sinha et al., 2005). Field evaluations further confirmed moderate-to-high suppression, with NSKE (5-10%), neem oil (0.5-1%) and azadirachtin products lowering dead hearts by 46-70% and causing 50-60% larval mortality (Jat et al., 2014, Chaudhary et al., 2016).

Synergistic enhancements are increasingly reported. For example, combining neem oil with *Metarhizium anisopliae* resulted in 68.5% reduction in leaf injury (Rathod et al., 2018), while karanj oil (1%) reduced dead hearts by >40% (Sharanabasappa et al., 2019). Phytochemical-rich botanicals such as *Melia azedarach* and *Annona squamosa* exhibit strong oviposition deterrence and larval toxicity due to high terpenoid content (Adati et al., 2021). Integrative approaches such as neem- or karanj-based formulations used with bioactive insecticides (spinetoram 25 SC, Spinosad 45 SC) have recorded 65-69% larval reduction and substantial yield gains (Singh et al., 2022). Similarly, azadirachtin (1500 ppm) in combination with entomopathogenic fungi such as *Beauveria bassiana* significantly improves larval suppression (71.3%) and enhances grain yield (Patil et al., 2023).

Recent advances in micro-emulsified neem and karanj formulations have demonstrated 58-72% larval reduction and 0.8-1.1 t/ha yield improvement with higher field stability and improved penetration (Sharma and Singh 2024). Botanicals particularly when integrated with microbial agents or selective biorational insecticides provide scalable, eco-safe and economically viable strategies for *C. partellus* management in maize (Abhishek and Yadav 2024).

Microbial Insecticides

Bacteria: *Bacillus thuringiensis* (*Bt*) remains one of the most reliable microbial tools for *C. partellus* management in maize. Early studies established the pathogenicity of *Bt* var. kurstaki against larvae, confirming strong efficacy on neonates and early instars (Jalali and Singh 2006, Deepthi et al., 2008). Commercial *Bt* formulations such as Dipel®, Biobit® and Delfin® consistently reduce dead hearts and stem tunnelling, providing moderate but reliable yield protection (Saini et al., 2020).

Synergistic combinations have gained importance in recent years. Integrating Bt with entomopathogenic fungi such as *B. bassiana* or *M. anisopliae* enhanced larval mortality to 55-72% and reduced tunnelling more effectively (40-60%) than single agents, an approach increasingly validated under field conditions (Kumela et al., 2022). *Bt*-botanical blends, particularly with azadirachtin (0.15-0.3%) have shown improved residual activity, enhanced feeding deterrence and higher early-instar mortality (Kaur et al., 2023) and enhancing yield by 1.2-1.8 q/ha (Feng et al., 2023, Irshad et al., 2023). Within agroecological systems such as push-pull, *Bt* interventions have been reported to achieve 86% reduction in infestation and significant yield gains (Midega et al., 2018). Transgenic Bt maize expressing *Cry* proteins continues to offer high levels of protection in regions permitting its cultivation, often achieving near-complete suppression of leaf and stem injury (Murenga et al., 2016, Gichuru et al., 2019). Advances in *Bt* formulations, synergistic microbial-botanical integrations and *Bt*-transgenic platforms reaffirm *Bt* as a cornerstone of sustainable *C. partellus* management.

Fungi: Entomopathogenic fungi, particularly *B. bassiana* and *M. anisopliae*, remain important microbial agents for *C. partellus* management. Earlier work confirmed their pathogenicity and larval susceptibility (Tefera and Pringle 2004), and recent research has strengthened evidence of their field-scale utility (Adhikari et al., 2021). Across multiple agro-ecologies, oil-based and aqueous formulations have consistently achieved 45-80% larval reduction, attributable to improved conidial persistence and environmental stability (Dhaliwal et al., 2018). A major advancement is the demonstration that *B. bassiana* and *M. anisopliae* can colonize maize endophytically, reducing larval feeding, delaying development and inducing systemic resistance (Tefera et al., 2016).

Compatibility with botanicals and other biocontrol agents enhances their integration within IPM programmes. Neem-based products show synergistic effects with entomopathogenic fungi (Togbe et al., 2014), while integration with egg parasitoids such as *Trichogramma chilonis* improves early-instar suppression (Deepthi et al., 2008). Synergy with Bt formulations further enhances larval mortality, especially under moderate infestation levels.

Physiological benefits such as enhanced plant vigor and activation of defense pathways have also been reported (Irshad et al., 2023). Overall, *B. bassiana* and *M. anisopliae* are promising eco-compatible tools for *C. partellus* management, with advances in endophytic delivery and formulation technologies strengthening their role in climate-resilient maize IPM systems.

Baculovirus: Nucleopolyhedroviruses (NPVs) have been explored as highly specific and environmentally safe biorational options against *C. partellus* (Sinha and Mohan 2014). Laboratory assays with *C. partellus* NPV (CpNPV) isolates demonstrate strong virulence, producing characteristic baculoviral pathology and achieving LC_{50} values of 1×10^5-10^7 OB/ml for neonates, with >90% mortality at 1×10^8 OB/ml (Kumar et al., 2011, Sinha 2014). Time-mortality studies further indicate that higher viral doses shorten larval survival periods, with LT_{50} values typically within one week (Ghosh and Chakraborty 2016). However, field efficacy is substantially lower due to rapid UV and temperature-induced degradation of occlusion bodies. Improved oil-based and UV-protectant formulations enhance viral persistence by 20-25%, extending residual activity from 2 to 5 days and improving practical effectiveness (Patel et al., 2017).

Granuloviruses (GVs) associated with *Chilo* spp. have also shown cross-pathogenicity to *C. partellus*, with 60-80% mortality at 1×10^7 OB/ml in feeding assays (Manjunath et al., 2018). Despite encouraging laboratory results, widespread deployment of CpNPV and GV formulations remains constrained by inconsistent field performance and limited commercial standardization. Advancements in UV-stable formulations, scalable production and multi-location field validation are essential for integrating viral biopesticides into climate-resilient maize IPM programmes.

Insect growth regulators (IGRs): Insect growth regulators (IGRs) offer an effective biorational option for *C. partellus* management by disrupting chitin synthesis or endocrine regulation, with generally low non-target effects. Field evaluations show that benzoylureas such as teflubenzuron and lufenuron, particularly when integrated with neem, reduce stem tunnelling and dead-heart incidence by 48-62% while conserving parasitoids like *Cotesia flavipes* (Muzeyi, 2005). Similarly, diflubenzuron (0.0125%) achieved 59% reduction in dead hearts and increased grain yield by 21.4 q/ha (Sadanandane et al., 2012).

Laboratory bioassays further demonstrate dose-dependent larval mortality, prolonged development and reduced adult emergence with lufenuron, while pyriproxyfen induces abnormal pupation and partial sterility (Hameed et al., 2016). Juvenile hormone analogues disrupt endocrine pathways associated with metamorphosis, suppressing adult emergence (Venkat Rao et al., 2016). Among ovicidal IGRs, hexaflumuron (200 mg/l) causes complete egg mortality, whereas lufenuron (1000 mg/l) delays hatching and produces >50% mortality of developing embryos (Achiri et al., 2017). Lufenuron and pyriproxyfen further reduce egg hatchability to 37.7% and 60.6%, respectively, often yielding malformed larvae and incomplete pupation (Aboelhadid et al., 2018). Integration of IGRs with *Trichogramma chilonis* releases increases parasitisation by 18-27% and reduces dead hearts by 20-35% (Patil et al., 2020, Ghosh et al., 2021). Population modelling indicates that lufenuron significantly lowers intrinsic rate of increase and adult longevity (Feng et al., 2023). Under field conditions, sequential applications of lufenuron (50 g a.i./ha) or diflubenzuron (25 g a.i./ha) reduced larval density by 64.9% and enhanced yield by 27% (Hameed et al., 2024). Collectively, IGRs alone or within IPM modules provide reliable, ecologically compatible alternatives to conventional neurotoxic insecticides for sustainable suppression of *C. partellus* in maize.

Semiochemicals and pheromones: Semiochemicals particularly sex pheromones are now integral to monitoring and decision-support systems for *C. partellus*. Pheromone trap catches closely reflect field population dynamics, enabling accurate forecasting, early warning and threshold-based interventions. Molecular studies on pheromone-binding proteins (PBPs) highlight their role in signal recognition and their potential for designing novel pheromone analogues through sequence analysis and molecular docking (Pedda Kasim et al., 2018).

Advances in pheromone chemistry and behavioral ecology have significantly enhanced application efficacy. Synthetic lures developed for *Chilo* spp. support mass trapping and IPM integration, achieving 60-90% suppression of infestation across cropping systems (Chen et al., 2013). Optimized lure ratios, dispenser types and release rates tailored to agro-climatic zones ensure consistent trap performance. Semiochemical-based surveillance also improves intervention timing, reducing unnecessary insecticide sprays and residues (Taneja et al., 2020). Electrophysiological and field evaluations confirm that the blend of (Z)-11-hexadecenal and (Z)-11-hexadecenol in a 100:100 ratio elicits maximum male attraction (Guleria et al., 2023). Maize-derived kairomones have further been shown to synergize pheromone response, supporting the development of hybrid kairomone-pheromone lures with enhanced sensitivity under low-density infestations (Guleria et al., 2021). Efforts should prioritize standardized trap densities, improved controlled-release dispensers and integration of pheromone surveillance with biological control, resistant cultivars and climate-responsive IPM models.

Emerging biorationals (RNAi and nanobiopesticides): Advances in molecular biotechnology and nano-formulations are expanding biorational options for managing *C. partellus*. RNA interference (RNAi) has shown promising gene-specific suppression, with transgenic maize expressing dsRNA against the chitinase gene (*CpCHI*) achieving 57-82% transcript knockdown and nearly 53% larval mortality (Adeyinka et al., 2023). Targeting chitin-synthase and metabolic genes similarly reduced larval growth and survival and induced deformities during pupation (Rana 2020). However, RNAi efficiency in lepidopterans is constrained by dsRNA instability and delivery barriers, encapsulation in nanoparticles or polymeric matrices enhances oral uptake, persistence and silencing efficiency (Nitnavare 2021, Lu 2023).

Nanobiopesticides have likewise advanced the performance of botanical and microbial agents. Nano-encapsulated azadirachtin formulations exhibit improved UV protection, stability and residual activity, resulting in stronger feeding deterrence and mortality compared with conventional formulations (Pasquoto-Stigliani et al., 2017). Nano-formulated fungal and plant-based biopesticides show 20-40% higher larvicidal activity and improved persistence under controlled trials (Lu 2023). Nanocarriers such as liposomes and clay nanosheets also protect dsRNA from degradation, enabling hybrid RNAi-nanotechnology platforms with enhanced delivery and efficacy (Nitnavare 2021).

CONCLUSION

Maize stem borer, *C. partellus* remains a key constraint to maize production across tropical and subtropical regions, with its polyphagy, overlapping generations and climatic resilience necessitating sustainable management approaches. Improved understanding of its bio-ecology and seasonal dynamics now supports more accurate forecasting and targeted interventions. Biorational tactics provide effective, environmentally compatible alternatives to conventional insecticides and their integration within robust IPM frameworks strengthened by digital advisory systems and extensive field validation offers a viable pathway for long-term management of *C. partellus* while conserving beneficial fauna and overall agro-ecosystem health. This review calls for further research on developing synergistic biorational consortia (microbial, botanical and pheromone-based), strengthening decision-support tools for precise application timing and evaluating long-term impacts on natural enemies. Policy support for residue-free maize and organic certification will further enhance adoption. Multi-location validation across diverse Indian agro-ecologies remains critical for achieving durable, scalable IPM solutions for *C. partellus.*

AUTHOR'S CONTRIBUTION

G. V. Suneel Kumar conceptualized the review, developed the framework, supervised literature synthesis and finalized the manuscript. S. V. S. Gopala Swamy organized and interpreted relevant findings and critically reviewed the content for accuracy and completeness. C. Kathirvelu conducted the literature search and assisted in drafting. All authors approved the final version.

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