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Distribution, Host Range, Damage Potential, Bioecology and Management of *Chilo partellus* (Swinhoe): A Review

***Ashok Kumar Sau*[*], K. Chandrakumara, Aditya K. Tanwar and Mukesh K. Dhillon**
Division of Entomology, ICAR-IARI, New Delhi, India.

*(Corresponding author: Ashok Kumar Sau***)*

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ABSTRACT: In natural and agro-ecosystem plants remain exposed to a wide range of biotic stresses, among which ubiquitous prevalence of insect herbivores is of prime importance. *Chilo partellus* considered to be one of the most important and widely distributed insect pests of maize and sorghum in Asia and Africa. It has good thermal plasticity which helps to adapt in new geographical areas of different environments, and spreading to new countries as invasive pest where it was previously not found. Its major host plant maize, one of the important cereal crops is grown across the globe, it can survive on wide range of cultivated and wild species of poaceae family so there is a risk of invasion into new areas because of adaptive trait in *C. partellus*. Facultative Diapause is an important adaptive trait in *C. partellus* for survival in adverse environmental condition. There is substantial role of food along with other abiotic factors such as temperature and photoperiod, in induction of diapause in C. *partellus*. All these favourable factors may help the *C. partellus* to invade, survive and dominate in new agroecosystems. Furthermore, its cryptic nature of feeding protects it from direct exposure to chemical pesticide and natural enemies. Maize is one of the important cereal crops occupying third rank globally in area and production next to rice and wheat. So, for global food security, sustainable management of *C. partellus* should be done.

Keywords: Cereal stem borer, *Chilo partellus*, Diapause, Bio-ecology, Management.

INTRODUCTION

Chilo partellus (Swinhoe) commonly known as spotted stem borer, is a major pest of maize and sorghum in Asia and Africa. By invading to new areas, it hampers maize production worldwide (Kfir *et al.*, 2002). In this review paper we are attempting to synthesize the information available on various aspects of *C. partellus* which could help in sustainable management of this pest and ensure global food security.

Origin and distribution. The *C. partellus* is native to Asia and from there it spread into eastern Africa in early 1930s (Tams, 1932) since than it has continuously expanded its presence in the warm, low-altitude regions of eastern and southern Africa (Kfir, 1997). In Asia it has widely distributed into India, Bangladesh, Cambodia, Indonesia, Pakistan, Sri Lanka, Thailand, Vietnam, Yemen, Afghanistan, Iran, and Laos, (Harris 1990). Based on biological attributes and biochemical profiles of *C. partellus* population from different locations of India, it was found that population from Hisar, Hyderabad, Parbhani and Coimbatore were distinct from each other, which indicated presence of four biotypes of *C. partellus* in India (Dhillon *et al.*, 2021). In Africa, it was first time reported from Malawi (Tams, 1932), and subsequently it has spread to Ethiopia, Kenya, South Africa, Botswana, Comoros Islands, Eritrea, Lesotho, Mozambique, Somalia, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe (Kfir *et al.*, 2002; Sylvain *et al.*, 2015). In Africa, *C. partellus* has proven to be an efficient colonizer, and it seems to be displacing the indigenous stem borers of sorghum and maize like *Busseola fusca* (Lepidoptera: Noctuidae) by rapidly expanding its geographical ranges (Kfir, 1997; Guofa *et al.* 2001; Ong'amo *et al.* 2006b). One of the possible reasons behind this displacement and expansion could be its three-week shorter life cycle and one-month shorter diapause period than *B. fusca* which gives it a further competitive advantage because of its higher potential rate of increase (Kfir, 1997; Dejen *et al.* 2014). Recently, it has also been reported from the moderately drier regions of the Mediterranean Basin in Turkey (Bayram and Tong˘a 2015) and Israel (Ben-Yakir *et al.* 2013). So, it has widely distributed in Asia and Africa, and also spread to the Mediterranean region. Furthermore, it has been predicted that there is substantial invasion risk of *C. partellus* to cropping areas in the Americas, China, Europe, Australia, New Zealand and West Africa by using CLIMEX model (Yonow *et al.*, 2017). So, it should be a pest of major concern to bio-security organisations in these uninvaded regions, and countries those are adjacent to currently infested regions in Africa and Asia.

Biology and behaviour on different hosts. Study on biological performance of *C. partellus* on six different maize genotypes in Northern India found that larval period, larval survival, pupal period, pupal weight, adult emergence and fecundity of 20-22 days, 51-78%, 5-6 days, 63-92 mg/pupae, 30-52%, and 192-554 eggs/female respectively (Bhoi *et al.*, 2017). It was reported that temperature, relative humidity (RH) and their interaction have significantly affected the developmental time, adult longevity and fecundity of the pest where developmental time was inversely related to temperature (Tamiru *et al.*, 2012). Biological study of *C. partellus* on six landraces and one hybrid variety of maize shows that larval preference was lower for the landraces compared to hybrid and significantly lower larval survival in landraces (32%) compared to hybrid maize (54%). Adult female of *C. partellus* preferred non-exposed maize landraces for subsequent oviposition which deters further colonisation by the herbivore, while in case of hybrid, there was no difference in oviposition preference (Mutyambai *et al.*, 2014) which shows different behavioural and physiological responses of *C. partellus* to different maize varieties. Study on the suitability of wild gramineous plants as hosts of *C. partellus* in comparison to a maize variety show significantly higher feeding and assimilation of food by larvae fed on maize than wild host. Also, larval growth and development were significantly faster on maize than wild host. However, there were no significant differences in oviposition preference but larval arrest and dispersal studies shows that from 77% to 88% first instar larvae were not recovered on wild host plant after three days (Mohamed *et al.*, 2004). Finding on mating among different age male and female adults of *C. partellus* shows that the increasing age of *C. partellus* females at the time of mating greatly reduces the hatchability and fecundity of eggs, and mating in early age reduced the longevity of males and females (Dhillon *et al.*, 2019b). Changing climatic scenario has implications for bio-ecology and population dynamics in *C. partellus*. In a diapause experiencing population of *C. partellus*, reduction in longevity, egg viability and fecundity were recorded which ultimately leads to a reduction in population growth parameters, but due to global warming if it does not enter in diapause than its population may increase faster (Dhillon and Hasan, 2018).

Host range and nature of damage in different crops. The spotted stemborer, *C. partellus* is a generalist herbivore and feeds on several species of cultivated and wild plants of Poaceae family (Ong'amo *et al.*, 2006a; Moolman *et al.*, 2014). It is the most damaging Lepidopteran pest of maize in Asia, eastern and southern Africa (Kfir *et al.*, 2002), causing significant losses in grain yields. Several reports confirm that the *C. partellus* is possibly a serious pest of maize and sorghum in Asia (Doharey, 1971; Ahad *et al.*, 2008; Dang and Harris 1990) and the most severe insect pest of maize and sorghum in eastern and southern Africa (Harris, 1990; Bate *et al.*, 1991; Sylvain *et al.*, 2015). It has also been described as a pest of rice (Harris, 1990), sugarcane (Assefa *et al.*, 2010, Harris, 1990), and pearl millet (Harris, 1990). The presence, abundance and intensity of infestation by *C. partellus* is influenced by both abiotic and biotic factors in different geographical region (Dhillon *et al.*, 2017). The newly emerged larvae of *C. partellus* prefers to feed on young leaves whorls causing scars and holes; then move towards growing point of plant and bore in the central whorl (Kfir *et al.* , 2002), which causes a characteristic symptom known as "dead-heart". However, the older larvae tunnel extensively in maize stem which causes lodging and interference with the grain formation (Kfir *et al.,* 2002).

Damage parameters and yield loss. Generally, understanding the relationship between damage parameters (foliar lesions, dead heart and stem tunnelling) and corresponding yield loss elucidates the most important yield reducing parameters. In case of *C. partellus* reduction in number of ears harvested in maize due to larval damage was primary cause of yield reduction. In a study it was found that the combined effect of ears and stem tunnelling accounted for 34-43% yield reduction while other traits cause less than 2% reduction (Ajala and Saxena 1994). It is one of the major biotic limiting factors of maize and sorghum productivity (Pingali and Pandey 2001; James, 2003). The *C. partellus* cause 18-25% yield losses in maize and sorghum under diverse agroclimatic conditions in Asia and Africa (Dhaliwal *et al.*, 2015). The Average avoidable yield losses caused by *C. partellus* were reported to be 13% to maize crop sown in month of June which calculated based on protection provided with chemical spray in Punjab, India (Dhaliwal *et al.*, 2018). The yield loss caused by *C. partellus* in Nepal was estimated around 28% in unprotected maize as compared to protected maize (Sharma and Gautam 2010).

Diapause strategy in *Chilo partellus*: Hibernation and aestivation. Diapause is a genetically determined adaptive scheme of insects to survive during predictable adverse environmental conditions when the resources needed for development, reproduction and population growth are lacking. It is arrest in development accompanied by suppressed metabolism and eventually lifting the arrest to resume development or reproduction (Denlinger, 2002). It is a seasonal dormancy and its expression is regulated by different environmental factors that precede and reliably foresee the arrival of unfavourable conditions for insect. It also helps the insects to match the activity cycles with the onset of optimum climatic conditions thus ensuring effective resource utilization (Yocum *et al.*, 2011). It is characterized by behavioral inactivity, slowing growth, and morphogenesis and reproductive functions arrest (Danks, 1987). During diapause normal progression of development is abruptly brought to a halt for many months and not to be resumed until favourable condition come. The capacity for diapause is widespread among insects that has contributed to their survival by allowing them to exploit seasonal resources and escape the harsh environmental conditions (Denlinger, 2002). The key feature of *C. partellus* bioecology is the arrangement of the facultative type of diapause (Dhillon and Hasan 2017a; Kfir *et al.*, 2002; Ofomata *et al.*, 1999). Full grown larvae of *C. partellus* enter diapause inside the old stems or stubbles which usually occur during host plant maturity periods (Ofomata *et al.*, 1999). In maize and sorghum agro-ecosystem, *C. partellus* have a dormancy duration of 45–50 days before termination of true diapause that matches its activity cycles with favourable conditions, thus ensuring effective resource utilization (Dhillon & Hasan, 2017a; Dhillon *et al.*, 2017). Larvae of *C. partellus* undergo estivation (summer diapause) under South parts of India (Trehan & Butani 1949). Dhillon *et al.* (2019a) concluded that the precise combination of temperature and photoperiod and food quality were essential for estivation in *C. partellus* and found that 32°C + 13L:11D along with dry food were optimum conditions for estivation induction in the laboratory.

General stages of diapause and its regulation. The insect undergoing diapause passes through a sequence of physiological events including diapause induction, maintenance, termination, and post-diapause development. Induction phase occurs when cues from the environment are sensed. During maintenance phase, the endogenous developmental arrest persists where metabolic rate is relatively low and constant. In termination phase Specific changes in environmental conditions cause decrease the intensity of diapause to its minimum level. (Kostal, 2006). In photosensitive phase, insects program their diapause based on sensitivity to daylength usually far in advance of the actual expression of diapause stage. The basic requirement is to distinguish the long days from short days (a clock) and to count the number of short days that have occurred (a counter). This temporal segregation has evolved to offer a period of preparation for diapause and events that occur during this phase are very important because failure to adequately prepare for diapause will reduce the chances of survival after the diapause. This period may enable the diapause-destined insect to locate a suitable place, sequestration of additional fat reserves (Adedokun and Denlinger 1985), deposition of extra layers of hydrocarbons for waterproofing the cuticle (Yoder *et al.*, 1992), or the synthesis of storage proteins (Chippendale, 1988). These additional fat and protein serve the nutritional requirement during diapause and source for the extensive tissue development that occurs immediately following diapause termination. At attaining the correct stage for diapause, the insect arrests its development and switches on the new metabolic machinery that will sustain it during metabolic suppression, and then at correct time it decides to resume development (Denlinger, 2002). Diapause is genetically determined, with the neuro-hormonal system as mediator. It is regulated by combination of environmental, hormonal and molecular regulation. (Denlinger, 2002). Degree of dominance estimates in *C. partellus* shown that diapause, developmental and morphometric traits are governed by over dominance gene effects, and mainly depend on parental diapause history (Dhillon *et al.*, 2020).

Diapause induction and termination factors. It is important to understand the influence of different factors on different diapause phases for predicting the onset and termination of diapause in the field. Among the different environmental factors, temperature and photoperiod are viewed as the key environmental factors which contribute in the developmental biology of arthropods (Haghani *et al.*, 2007). Moreover, temperature and photoperiod play a very important role in deciding the type of diapause either hibernation or aestivation (Dhillon *et al.*, 2017, 2019a; Dhillon and Hasan, 2017b). Each phase of diapause is strongly affected by photoperiod and temperature (Tauber *et al.*, 1987; Danks, 1987). Different combination of these factors affects the seasonal adaptation, regulate the ecological, behavioral and physiological activities in insects (Roy *et al.*, 2002). Scheltes (1978) investigated three plant factors; water, soluble sugar and crude protein in relation to diapause and found that diapause could be "artificially" induced in non-diapause larvae by introducing it into aged maize stems. The rice stem borer, *Chilo suppressalis* (Walker) as fully grown larvae enters facultative diapause in response to short-day conditions. It was found that the third instar of larvae was most sensitive to the photoperiod, and night length played an essential role in the initiation of diapause (Xiao *et al.*, 2010). The seasonal changes together with host plant maturity enforces North Indian *C. partellus* population larvae to undergo hibernation, where as in South India it enters aestivation (Dhillon and Hasan 2017a).

Generally, termination of diapause is affected by a combination of high temperature and a long day photoperiod. Long days accelerated pupation (upto 16 hr daylength), and provision of artificial diet not have any effect but water decreased the time to pupation. Under laboratory condition of 28^{o} C temperature, 16 h daylength and availability of water, *C. partellus* diapausing larvae pupated in about 9 days by termination of diapause (Kfir, 1993).

Biochemical, Morphological and biological changes during diapauses. Various changes such as suppression of development and reproductive function, and increase in metabolic reserves could occur when insect undergoes diapause (Irwin and Lee 2000; Jiang *et al.*, 2010). Studies to measure the changes in amino acid and lipophilic profiles of *C. partellus* larvae show higher amounts of amino acids (namely; serine, glycine, histidine, arginine, proline, tyrosine, and methionine) in estivation, while lower in hibernation as compared to non-diapause larvae. The lipophilic compounds also have variability in hibernation and estivation with non-diapausing stage (Tanwar *et al.*, 2021). Larvae of *C. partellus* totally lack cuticular pigmentations, markings, spots, and asetose tubercle during diapause stage. Intermediate of non-diapausing and diapausing larvae are less conspicuously pigmented (Dhillon & Hasan 2017a). Longer the larvae remained in diapause, the lighter in weight the emerging moths were, with fewer eggs and oocytes (Kfir, 1991). A significant decrease in body weight, size and head capsule width in diapause larvae were reported, with smaller pupal and adult sizes (Dhillon & Hasan 2017a). During diapause, larvae of *C. partellus* progressively decreased in weight at the rate of 4.5 mg per week, lost 50% of their initial body mass and had up to seven stationary moults, became less active and lost pigmentation (Kfir, 1991).

MANAGEMENT OF *Chilo partellus*

EIL in maize. The economic injury level (EIL) of *C. partellus* on maize at four different stages of crop growth stages were calculated in India. EIL was found to increase as the age of crop infestation increases, being low at 12 and 17days old plants (1.24 and 1.38 larvae/plant) but higher on 22 and 27days old plants (2.56 and 3.36 larvae/plant) (Sharma and Sharma 1987). In Kenya EIL was calculated on 20, 40 and 60days old maize plant by releasing varying density of *C. partellus* larvae and it was found to 3.2 and 3.9 larvae/ plant for 20 and 40 days old plants, respectively. Maximum yield reduction and stalk damage reported to the 20-day old crop, while effect on yield was insignificant for the 60-day old crop (Reddy and Sum, 1991).

Role of host plant resistance and genetic engineering. Variation in performance and abundance of herbivorous insects is attributed to variation in host plant quality, being determined by nutritional composition, allelochemistry and specific anatomical features. In non-preference type mechanisms of resistance, plants possess characteristics which inhibit insect responses such as orientation, feeding, and ovipositional, while antibiosis mechanisms of plants would involve the metabolic responses of plant to insect such as provide inadequate nutrients or metabolic inhibitors to cause failure of larval development, survival, egg production, and hatching of the eggs (Kumar, 1997). Considerable genetic variability amongst the sorghum genotypes for different types of damage caused by *C. partellus* were reported and study also found that criteria such as resistance to leaf feeding, deadheart formation, stem tunnelling and/or compensation in grain yield can be selected for use in sorghum improvement (Singh *et al.*, 2012). Significant genetic difference among landraces in terms of their growth, tolerance, and constitutive resistance to *C. partellus* were reported in twenty *Sorghum bicolor* landraces from the tropics, suggesting that it is possible to enhance both tolerance and resistance defence strategies in *S. bicolor* to *C. partellus.* Study on resistance of maize to *C. partellus* found that selected genotypes (CPM 2, CPM 8, CPM 13, CPM 15 and CPM 18) having variable morphological traits (leaf glossiness, anthocyanin pigmentation and seedling vigor), had significantly lower dead-hearts and more adverse effects on biological parameters of insect compared to the resistant check (CML 334) which pooled together shows antibiosis mechanism of resistance (Dhillon and Chaudhary 2015). Certain amino and fatty acids play essential role in plant–herbivore interactions and induction of antibiotic defence in plant to herbivore. Study on amino acid profiling suggests that Cystine and Proline contents in sorghum seedlings, and Alanine, Cystine, Glycine, and Proline contents in *C. partellus* larvae have significant and negative association, and contribute to explain >90% variability in antibiosis to *C. partellus* (Dhillon and Kumar 2017). The fatty acids such as myristic acid, methyl 3-methoxytetradecanoate, palmitic acid, stearic acid and squalene found in both sorghum plant and *C. partellus*, could be used as biomarkers for *C. partellus* interactions (Dhillon and Kumar 2020). In maize plant, amino acids viz., aspartic acid, glycine, histidine, lysine, phenylalanine, proline, and serine; and the fatty acid, stearic acid showed significant association with various development parameters against *C. partellus*, could be used as biomarkers to identify resistant maize genotypes (Yele *et al.*, 2021). It was reported that significantly poor survival and development of *C. partellus* on white and yellow kernel maize genotypes than that on QPM and sweet corn genotypes which shows their resistance to spotted stem borer (Yele *et al.*, 2019).

Transgenic Bt maize can help to manage several species of Lepidopteran stem borers including *C. partellus* (Tefera *et al.*, 2016; Tende *et al.*, 2010). Study in Uganda shows that Bt maize (MON810) with Cry1Ab was protected against leaf damage and limited stem borer entry into maize stems. It was also reported to be effective in controlling *C. partellus*, also 30–80% higher yield than non Bt hybrids. In India, Bt maize is not allowed to be cultivated. Transgenic sorghum plants expressing a synthetic *cry1Ac* gene under control of a wound-inducible promoter from the maize protease inhibitor gene (*mpiC1*) found up to 60% reduction in leaf damage, 40% larval mortality, with the surviving larvae showing a 36% weight reduction over those fed on control plants (Girijashankar *et al.*, 2005).

Behavioral management: ecological engineering. Farming systems for pest control based on the simultaneous stimulo-deterrent diversionary strategy or called push–pull system used for pest management. A prominent example is from sub-Saharan Africa for smallholder farming cereal production against lepidopterous stem borers. (Pickett *et al.*, 2014). Napier grass (*Pennisetum purpureum*) used as animal fodder having potential role as a trap crop in the management of *C. partellus* through habitat manipulation. It was reported that gravid female moths preferentially chose Napier grass for oviposition over a susceptible maize cultivar. Larval survival was significantly lower (about 10%) on the majority of the Napier grass varieties, also larval development took 2 more weeks (Khan *et al.*, 2006). Napier grass were more preferred by the borer moths for oviposition and allowed minimal survival of the larvae which also desirable for conservation of natural enemies. In a recent study Brachiaria grass (Poaceae) were also reported as a trap crop for *C. partellus*. The female prefers brachiaria plants over maize for oviposition and brachiaria plants have negative effects on subsequent larval survival and development. No larvae survived on brachiaria plant tissue more than 5 days, while 79% of the larvae survived on maize (Cheruiyot *et al.*, 2018). This technique is even more efficient in case of *C. partellus* due to specific host plant selection behaviour of this insect which increase the effectiveness of a trap crop. Here, female moths have oviposition preference for napier grass which is not a good food for larvae, but larvae did not have any clear behaviour to reject it. So, Napier grass is beneficial for trap cropping in management of this pest, (Midega *et al.*, 2011). Further, it was reported that predation rates of the *C. partellus* eggs were significantly higher in the ‘push – pull’ than in the maize monocrop plots which so the biocontrol of this pest on maize crop is more efficient in push-pull strategy (Midega *et al.*, 2006). Soil conditioning through companion cropping in an agricultural ecosystem can have impact on growth rate and chemical phenotype of maize which have negative effect on pest performance by suppressing larval feeding. This new mechanism of associational resistance further increases the effectiveness of push-pull companion cropping system to manage insect pests (Mutyamba *et al.*, 2017). So, both above mentioned plants can be used as trap crop around the maize field and *Desmodium* spp. (Fabaceae) plant can be planted in-between to repel the adult moth of this pest for sustainable management of *C. partellus*.

Biocontrol agents: microbial bioagent and parasitoids. Biological control with microbial pathogens offers an alternative method of controlling the pest. The efficacy of 3 formulation of *Beauveri*a *bassiana* against *C. partellus* were tested and found that both aqueous and dry rice grain-based inoculums showed good result in reducing larval population, foliar damage, and stalk tunnel length (Maniania, 1993). These formulations are easy to apply and manage the *C. partellus* at small scale level can developed by using other cheap and locally available raw materials. Careful selection of fungal isolates for use as microbial control agents is important. Laboratory tests have identified four strains (*B. bassiana* ICIPE 35 and 4, and *M. anisopliae* ICIPE 18 and 30) which were found to be highly pathogenic to *C. partellus* among 15 strains tested (Maniania, 1992). Use of more than one pathogen provides even better control. Combined application of *B. thuringiensis* and *B. bassiana* could be a cost-effective and eco-friendly approach for the successful management of *C. partellus*. Application of *B. bassiana* (1×10^8 spores/ml) and *B. thuringiensis* (0.75µg/g) together exhibited highest larval mortality of larvae while the 2nd instar larvae were more susceptible to it than 4th larval instars (Sufyan *et al.*, 2019). *Chilo partellus* Nucleopolyhedrosis virus (CpNPV) belonging to the family Baculoviridae which was isolated from diseased larvae of *C. partellus* were found to cause larval mortality with typical symptoms of viral infection in *C. partellus* (Sethuraman and Narayanan 2010).

The different stages of *C. partellus* attacked by a wide array of parasitoids in natural condition and some of them are commercially used manage this pest in ago-ecosystem. Egg parasitoids, *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) are widely used against lepidopteran insect-pests. Study from Bangalore, India shows that parasitism rates by *T. chilonis* on *C. partellus* eggs were up to 63% with significantly reduction in stem tunnelling when parasitoids releases at 5 days interval. Furthermore, the combined application of *T. chilonis* and *B. thuringiensis* resulted in significantly less pest infestation and stem tunnelling compared to individual treatments (Jalali and Singh 2006). Recent study from northern India shows that maximum egg parasitism of *C. partellus* with effective suppression of maize plant infestation, dead heart and leaf injury when *T. chilonis* were released twice at 7 and 14 days after germination @ 1,25,000 parasitized eggs per ha. (Singh *et al.*, 2020). In southern India, larval parasitoid, *Cotesia flavipes* in *kharif* season (29% parasitization) and *Sturmiopsis inferens* in *rabi*-summer season (28%parasitization) was found to be very active, while population of 2% pupal parasitoid, *Tetrastichus* sp., was also recorded during kharif season on *C. partellus* (Divya *et al.*, 2009). It was reported that *C. flavipes* have better functional and numerical responses on *C. partellus* than *Cotesia sesamiae* in Kenya (Sallam *et al.*, 1999). The global climate change may alter the resistance to temperature stress in insects which could affect biocontrol efficacy. Phenotypical plastic responses are important mechanism for an organism to survive when faced with novel environments (Nyamukondiwa *et al.*, 2010). Study suggest that thermal plasticity may enhance the survival of *C. partellus* and *C. flavipes* when they are exposed to lethal low and high temperatures which helps to potentially mediate the interaction between them in rapidly changing environments, however, *C. partellus* appeared to be more plastic, and may inhabit slightly warmer environments than *C. flavipes* (Mutamiswa *et al.*, 2018).

Efficacy of insecticides in India

Bio-efficacy of insecticides on *C. partellus* was tested and found minimum percent infestation recorded in chlorantraniliprole 20 SC @ 0.3 ml/l while maximum benefit: cost ratio (14:1) was found in flubendiamide 480 SC @ 0.2 ml/l treatment (Kumar and Alam, 2017). Study on efficacy of tetraniliprole 480 FS as seed treatment on *C. partellus* in maize crop results revealed that the insecticidal dose of 3.6 g/kg of seed found to provide maximum control while 1.2 and 2.4 g/kg of seed found safe to natural enemies of *C. partellus* among different dose treatment (Alam *et al.*, 2020). Another study done in Gujrat, India found that Spinosad 45SC @ 0.002 % and Chlorantraniliprole 18.5 SC @ 0.006% were found highly effective in reducing the larval population of *C. partellus* and dead heart in maize (Devananda *et al.*, 2018).

Study evaluated the lethal and sublethal effects of twelve insecticides on parasitoid *C. flavipes* indicated that based on residual toxicity test organophosphates exhibited highest contact toxicity to adults (LC_{50} 0.60-1.05mg a.i/l), while neonicotinoids were less toxic (LC_{50} 1.30-139.00 mg a.i/l), and sugar-insecticide feeding bioassays showed that organophosphates, pyrethroids and carbamates were highly toxic to adults and caused 100% mortality at 48 h of exposure in *C. flavipes*. Imidacloprid and acetamiprid were the least toxic to this parasitoid so they can be used in sustainable control of *C. partellus* (Akhtar *et al.*, 2021). Report on whole genome sequencing of *C. partellus* reveals multiple genes encoding different enzymes for detoxification of insecticides. Total 64 cytochrome P450 genes (CYP450s), and 36 glutathione S-transferases genes (GSTs) were identified which primarily responsible for xenobiotic metabolism in insects. In *C. partellus* genome total 183 circadian genes with and 11 olfactory receptor genes that mediate chemical cues were found. Target receptors related to insecticide action, 4 acetylcholinesterase (AChE), 14 γ aminobutyric acid (GABA), and 15 nicotinic acetylcholine (nAChR) receptors were also detected (Dhillon *et al.*, 2022). These information's will be useful for deployment of selective insecticides for the control of *C. partellus*.

CONCLUSION AND FUTURE SCOPE

The *C. partellus* is economically harmful for maize and sorghum agro-ecosystems worldwide, and has potential to spread in newer areas. Cryptic nature of feeding makes it difficult to manage through even chemical control, and there is a need to identify newer insecticide molecules with different mode of action, efficient biocontrol agents adapted to changing climatic conditions and stale sources of resistance in host crops for the management of *C. partellus* and sustainable crop production. The greater understanding on diapause physiology and associated reproductive fitness will also help in mapping the seasonal distribution patterns and off-season survival. Gene expression patterns linked with different phases of diapause, and insecticide action also need to be studied keeping in mind the presence of different biotypes.

Conflict of Interest. Nil.

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