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Review on bionomics and management of rice stem borer

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Abstract
Rice (*Oryza sativa* L.**)** is used as staple food for the overwhelming majority of the world's population. Rice production hampered mostly by stem borers like, yellow stem borer (*Scirpophaga incertulas*) pink stem borer (*Sesamia inference*), dark headed stem borer (*Chilo polychrysus*), stripped stem borer (*Chilo suppressalis*). For minimize the infestation farmers use different resistant rice cultivars like, TKM 6, PTB 10, Su Yai 20, Mudgo, DV 139, Taitung 16, Gontra Bidhan 3, MTU-2020, IR 50, NDR-97, etc. against stem borer population. For controlling deleterious pest population farmers mostly use insecticide which exhibit good results than any botanicals against rice pests. Other techniques including using microbial pesticides, other biocontrol agents, use of pheromones or allomones, staggered planting, synchronized planting, removal of infected leaves, steams with pruning shears, using of trap crop, etc. are effective for control rice pests. But indiscriminate use of chemical insecticides results in great economic loss with destabilizing of biodiversity and resulting cross resistance against insecticides. So, pest population ecology based sustainable management strategies of such pest species is very essential for climate smart pest management (CSPM) as well as climate smart agriculture (CSA) of rice and other crops in the near future.

Keywords: *Oryza sativa*, stem borer, sustainable management strategies, CSPM, CAS

1. Introduction

Rice (*Oryza sativa* L., Gramineae or Poaceae, 2n=24.) is used as staple food for the overwhelming majority of the world's population (Adhikari *et al.*, 2012) [5]. About 90% of rice in the world is grown and consumed by the population of the Asian countries (Samanta *et al.*, 2014) [80]. Rice accounts for nearly 42.5% of total food grain production in India (Arora *et al.*, 2019; Dutta and Roy, 2016; Ghule *et al.*, 2008) [9, 38, 43]. In West Bengal presently the crop is grown in 59.35 lakh hectare areas with a production of 150.37 lakh tonnes (Chattopadhyay *et al.*, 2008) [23]. Nearly 63% of total irrigated area of West Bengal yields approximately 15.48% of India's rice production (Dey *et al.*, 2005) [36]. Plains of West Bengal offer diversified agro-ecological conditions for cultivation of about 124 cultivars of rice (Adhikari *et al.*, 2012) [5]. In West Bengal, rice is grown in three different cropping seasons such as Aus (autumn rice), Aman (winter rice) and Boro (summer rice). Among them rate production during Aman (winter rice) crop season, is relatively high, followed by Boro (summer rice) and Aus (autumn rice) crop season (Sinha and Mishra, 2013) [91]. In fact, insect pests are among the most important biological constraints limiting rice yield potential and reflect large scale reduction both in quality and quantity throughout the world (Adhikari *et al.*, 2012; Arora *et al.*, 2019; Baharally and Simon, 2014; Banerjee *et al.*, 2018) [5, 9, 12, 14]. Rice production in West Bengal hampered by many biotic stresses mostly by rice insect pests like stem borer (yellow stem borer, *Scirpophaga incertulas*, pink stem borer, *Sesamia inference*, dark headed stem borer, *Chilo polychrysus*, stripped stem borer, *Chilo suppressalis***)**, leaf folder (*Cnaphalocrocis medinalis*), plant hoppers (*Nilaparvata lugen*s, *Sogatella furcifera*), leaf hopper (*Nephotettix virescens*, *N. nigropictus*), rice hispa (*Dicladispa armigera*), rice bug (*Leptocorisa acuta*, *L. oratorius*), gall midge (*Orseolia oryzae*), etc. which cause about 9.5% of total production loss either caused directly during different stages of life stages or by indirectly transmitting different viruses (Dhaliwal *et al.*, 2010; Dutta and Roy, 2016; Rajesh *et al.*, 2018; Sarkar *et al.*, 2016) [37, 38, 75, 83].

Farmers generally use broad-spectrum synthetic pesticides (Krishnakumar and Visalakshi, 1989; Tigga *et al*., 2018) [89, 93], few biopesticides (Sankar and Rani, 2018) [84] and several biorationals (Chakraborty, 2011; Chatterjee and Mondal, 2014; Elanchezhyan and Kumar, 2015) [20, 22, 41] pheromon trap (Dang *et al.*, 2016) [32] and other strategies in controlling these pests (Dhaliwal *et al.*, 2010; Koul *et al*., 2014; Padhan and Raghuraman, 2018) [37, 54, 66].

There are several other modern strategies like selection of high yielding resistant varieties, sterile male technique by irradiation or genetically engineered pests in management of respective pest species in the field as alternate management process with several constrains and limitations (Mobarak *et al*., 2020; Roy, 2019, 2020, 2021) [62, 77-79]. But unfortunately, even today, growers use all the management techniques injudiciously for even a single pest observation without considering any economic threshold levels (ETLs) limit or irrespective of pest population growth rate which always create ecological imbalance (Dutta and Roy, 2016; Jeevanandham *et al.*, 2020) [38, 52].

These result into secondary pest outbreak, pest resurgence, development of pesticide resistance and emergence of new pest biotypes, which ultimately leads regulatory complications in the agro ecosystem (Carvalho, 2017; Dutta and Roy, 2018; Mobarak *et al*., 2020) [18, 39, 62]. To face this ecosystem crisis, population based time specific sustainable management of rice pests are very crucial for climate smart pest management (CSPM) as well as for climate smart agriculture (CSA) of rice and other crops (Chávez *et al*., 2018; Jeevanandham *et al.*, 2020; Mobarak *et al*., 2020; Roy, 2020, 2021) [27, 52, 62, 78, 79].

2. Status of Rice Cultivation

Rice, a self-pollinated crop, is considered as the second most cultivated cereal crop (next to wheat) in the world providing 23% of global human per capita energy and 16% per capita protein which ranks high in nutritional quality among cereals (Adhikari *et al*., 2019; Hamsein *et al.*, 2020) [6, 44]. It is one of the most important food crops of about 80% people of West Bengal (Adak *et al*., 2020; Adhikari, 2004) [2, 3]. In West Bengal, rice is grown in three different cropping seasons such as Aus (autumn rice), Aman (winter rice) and Boro (summer rice). Among them rate production during Aman Crop Season, is relatively high, followed by Boro and Aus crop Season (Sinha and Mishra, 2013) [91]. In six agro-climatic zone of Bengal contains a huge amount of high yielding varieties have grown both under rainfed (upland and lowland) and irrigated (medium land) conditions along with a huge number of traditional or local rice and aromatic germplasms mainly under rainfed lowland (Ghosh *et al.*, 1993; Sinha and Mishra, 2013) [42, 91]. West Bengal is the richest reservoir of rice bio-diversity and the rice bowl of the country (Adhikari *et al.*, 2012) [5]. Beside that Basmati, Badsabhog, Gobindabhog, Tulaipanji, Kalonunia like aromatic rice varieties possess exemplary quality traits like aroma, fluffiness and taste (Samanta *et al.*, 1999, 2020) [81, 82]. The rice growing areas in West Bengal generally experience many biotic and abiotic stresses during different stages of crop growth almost every year (Nutter *et al*., 1993) [65]. Abiotic stress like floods, land erosion and other natural calamities often affect crop production but biotic stress causes 33% production loss in West Bengal, where the major pest weed causes 12.5%, insect pest 9.5% and disease 6.5% and other pests 4.5% in an average (Adak *et al.*, 2020, Sinha and Mishra, 2013) [2, 91].

3. Status of rice stem borer

The rice crops has infested by several Lepidopteran stem borer (SB) species like yellow stem borer (YSB), *Scirpophaga incertulas* (Walker) (Chakraborty and Deb, 2008) [21], Pink stem borer (PSB) *Sesamia inference* (Walker) (Rajesh *et al.*, 2018) [75], Dark headed stem borer (DSB) *Chilo polychrysus* (Walker) (Neupane, 1990) [64], Stripped stem borer (SSB) *Chilo suppressalis* (Walker) (Easwaramoorthy and Nandagopal, 1986) [41]. The SBs are key group of insect pests of rice and they have shown geographical variation in its species composition. Plains of West Bengal offer diversified agro-ecological conditions enduring a congenial environment for rice cultivation but it found to be infested by different stem borers (SBs) as described below (Table 1, 2).

3.1 Yellow Stem Borer (YSB): YSB, *Scirpophaga incertulas* (Walker) occurred maximum during flowering stage (Chakraborty and Deb, 2008) [21]. Adult female were laid about 150-180 eggs mainly on middle to upper the abaxial leaf surface (Hamsein *et al.*, 2020) [44] or on tip of leaf blade and covered with buff coloured hairs (Bhatt *et al.*, 2018**)** [16]. After 5-10 days of hatching larvae get dispersed with the help of silken threads and wind and bore into the rice stem and feed on the internal tissues of the stem and undergo 5-6 moults during 20- 40 days depending upon the climatic conditions (Dutta and Roy, 2018; Panigrahi and Rajamani, 2008**)** [39, 68]. Pupation takes place for 6-12 days inside a whitish silken cocoon (Bhatt *et al.*, 2018; Jasrotia *et al.*, 2019**)** [16, 51]. Notorious YSB encompasses Egg, Larva, Pupa and Adult (Hamsein *et al.*, 2020; Panigrahi and Rajamani, 2008) [44, 68]. This notorious pest encompasses egg, larva, pupa and adult stages in 31-42 days (Bhatt *et al.*, 2018**)** [16] and complete 4 to 6 generations each year (Jasrotia *et al.*, 2019**)** [51]. (Table 1).

Damage has encountered by newly hatched larva due to internodal penetration during vegetative phase specially in booting or flowering stage resulting the central leaf whorl does not unfold and turns brownish and dries off although the lower leaves remain green healthy with that during the reproductive stage of plant cause development of empty or partially filled grain (Bhatt *et al.*, 2018) [16] as a result central leaf turns brownish and dries out although the lower leaves remain green and healthy, a condition known as dead heart (DH**)** and drying out of panicles and empty panicles are very conspicuous in field as they remain stiff, straight, whitish and are called white ears or white head (WH**)** (Dutta and Roy, 2018) [39].

Economic threshold level has recorded 5 to 10% damaged tillers or dead hearts (Asghar *et al.*, 2009; Cork *et al.*, 1998) [11, 31] (Table 1).

Adult and larval activity deleterious pests has been recorded mostly on rice *Oryza sativa* but also to aggregate on maize and some wild grasses *Paniculum* spp, *Echinochloa sp*. *Cyperus rotundus*, *Cyperus revifolioides*, *Dactylis glomerata* etc. grown in and around paddy fields before rice flowers (Chopra *et al.*, 2017, Dutta and Roy, 2018) [29, 39]. (Table 2).

3.2 Pink Stem Borer (PSB): PSB, *Sesamia inference* (Walker) occurred maximum during tillering stage

(Jeevanandham *et al.*, 2020) [52]. Pink stem borer (PSB) *Sesamia inference* (Walker) has encompassesed egg, five instar (Chaudhari *et al.*, 2018) [24] to eight larval instar, pre pupa, pupa and adult (Bhatt *et al.*, 2018) [16] in 35-57 days, (Singh and Kular, 2015) [90] and completed 4 to 5 generations in average in each year (Jeevanandham *et al.*, 2020) [52]. Female of this notorious pest has laid rounded, pale and yellowish green coloured eggs in clusters in 2 to 3 longitudinal rows (Baladhiya *et al.*, 2018; Chaudhari *et al.*, 2018; Jeevanandham *et al.*, 2020) [13, 24, 52] within the cover of the leave sheath and in between the leaf sheath and stem (Bhatt *et al.*, 2018) [16]. After 5-7 days larva comes out and bore into stem and feed upon tissues of the stem (Chaudhari *et al.*, 2018) [24]. This deleterious pest has undergone 6 to 8 metamorphic stage, pre pupal and pupal stages in 21-39 days, 1-2 days and 8-14 days respectively (Bhatt *et al.*, 2018; Chaudhari *et al.*, 2018) [16, 24]. The damage to rice crop is mainly caused by larva which remain inside or behind the leaf sheath in groups and feed on the epidermal layer of the leaf sheath, results in formation of oblong holes in parallel rows in the unfolded leaves but during severe period tunnelling occurs on leaf blades and plants shows ragged appearance (Baladhiya *et al.*, 2018) [13]. Panicle initiation and milky grain stage leads to production of partially filled or empty grains and affected panicles appear white and infected plant produces dead hearts or white ear heads (Bhatt *et al.*, 2018) [16].

Economic threshold level has recorded 5-10% damaged tillers or deadhearts (Catling *et al.*, 1978) [19] (Table 1).

Besides that it was found infesting on other host plants like wheat, maize, *Eleusine indica*, *Eriochloa procera*, *Cymbopogon citratus*, *Cyperus rotundus*, *Echinochloa colona*, *Echinochloa crusgalli*, *Setaria pumila*, *Echinochloa frumentacea*, sorghum, sugarcane, guinea grass, *Scirpus maritimus*, *Paspalum scrobiculatum* and *Saccharum arundinaceum* (Jeevanandham *et al.*, 2020; Singh, 2012) [52, 89]. (Table 2).

3.3 Stripped Stem Borer (SSB)

SSB, *Chilo suppressalis* (Walker) just after YSB and PSB was responsible for 1% to 19% yield loss in early planted and 38% to 80% in late transplanted rice crops (Bhatt *et al.*, 2018) [16]. Female of stripped stem borer laid naked, scale like and translucent white to dark yellow eggs in clusters in several overlapping rows on leaves (Pathak and. Khan, 1994) [69]. After 7.7 days hatched into active larva (Chaudhari *et al.*, 2018) [24], which encompasses four developmental moulting stages in 23-39 days (Bhatt *et al.*, 2018) [16] and undergone diapause in stubbles to pupate without the silken cocoon and lasted 7 days to became adult. The life cycle is completed in 35-60 days (Ueno *et al.*, 2006) [95] and capable to complete upto 2 generation in each year (Luo *et al.*, 2016) [103]. (Table 1).

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3.4 Dark Headed Stem Borer (DSB):

DSB, *Chilo polychrysus* (Walker) occurred during dough stage (Bhatt *et al.*, 2018) [16]. Similarly notorious dark headed stem borer (DSB) encompasses egg, larva, pupa and full grown adult in 35 to 57 days (Pathak and. Khan, 1994) [69]. Similarly female of dark headed stem borer (DSB) *Chilo polychrysus* (Walker) had laid flat, oval, creamy white lay eggs in masses on upper and lower surface of leaves which hatch into active larva and by encompassing three instar larva, pupa and full grown adult stage in 26 to 61 days (Bhatt *et al.*, 2018) [16] and about six successive generations may develop in a year (Islam and Karim, 1997) [49] (Table 1).

Damage occurred during larval development which bore into growing points resulting central leaf fail to unfold and affected tillers fail to bear panicle and in later stage of plant growth, larval feeding causes, empty panicle or half-filled grains (Bhatt *et al.*, 2018) [16]. Initial boring and feeding of leaf sheath cause broad, longitudinal, whitish, discoloured areas at feeding sites called white heads but only rarely do they result in wilting and drying of the leaf blades which becomes yellow called dead heart (Pathak and. Khan, 1994) [69]. Economic threshold level for this notorious pest has recorded 2-8% hill or damage tillers (Way *et al.*, 1991) [97]. Beside rice plant this host also aggregated on sugarcane, maize, *Vetiver zizanioides* and other grassy weeds (Bhatt *et al.*, 2018; Neupane, 1990) [16, 64]. (Table 2).

4. Management Strategies

In this modern era with increasing human population there is a need to increase rice production per unit of land through sustainable management strategies (Aryal *et al*., 2018; Bhatt *et al.*, 2018; Chávez *et al*., 2018) [10, 16, 27]. To minimize yield losses and to increased productivity farmers use different management strategies with minimum cost to control pest population in agro ecosystem as described below (Basanth *et al.*, 2013; Das *et al.*, 2012; Roy, 2019) [15, 33, 77] (Table 3).

4.1 Chemical Control

Presently use of synthetic pesticides is the most popular method for the control of these rice pests (Basanth *et al.*, 2013) [15]. Application of soil granular and spray formulation of Acephate, Fipronil, Dursban (Chlorpyrifos), Convoy (Quinalphos), Carbofuran, Fipronil, Carbosulfan (Hurali *et al.*, 2020; Islam *et al.*, 2013) [47, 48], Fenvalrate, Thiamethoxam, Spinosad, Chlorantraniliprole and Carbofuran (Baladhiya *et al.*, 2018) [13] were effective against adult and larva of yellow and pink stem borers population (Rahman *et al.*, 2020; Zhao *et al.*, 2019) [74, 102]. Spray formulation of Carbofuran, Fipronil, Diazinon, Disulfoton Padan, TXH09 (Khan *et al.*, 2020) [53], Deltamethrin, Spinosad, Lambda-cyhalothrim, Emamectin-benzoate, Indoxacarb, Chlorpyrifos-ethyl were very cost effective agent for managing adult and larval incidence caused by herbivores dark headed and stripped Stem Borer (Achiri *et al.*, 2020; Zhao *et al.*, 2019) [1, 102] (Table 3).

4.2 Biochemical Control

Plant formulation also seemed effective and having Natural plant products like extract of Neem (*Azadirachta indica*), Tobacco (*Nicotina tobacum*) Karanja (*Pongamia glabra*) (Islam *et al.*, 2013) [48] etc has shown good efficacy against deleterious pest incidence caused by stem borers (Rahman *et al.*, 2020) [74]. Extract of rice variety TKM-6, Pentadecanol TKM-6 were effective against *Chilo suppressalis* (Prakash *et al.*, 2008) [73]. Oil formulation of Neem oil, Mahogany (*Swietenia macrophylla*) oil, Karanj (*Pongamia pinnata*) (Majlish *et al.*, 2015) [61], Eucalyptus (*Eucalyptus obliqua*), Cedar Wood, Palmarosa, Jatropha, Mahua (*Madhuca longifolia*), Pinnai (*Calophyllum inophyllum*) Citronella, Vetiver, Catnip (Koul *et al*., 2014) [54] were effective against stem borer incidence (Rahman *et al.*, 2020) [74] and shown minimal residual activity against beneficial insect populations (Koul *et al*., 2014) [54]. Like plant extracted component animal derived Cow urine also act as an antifeedant against herbivorous stem borer (Shukla *et al.*, 2003**)** [88].

4.3 Biological Control: Mycobial powder and isolate extract from *Bacillus thuringiensis, Trichogramma japonicum* (Upamanya *et al.*, 2013) [96], *T. chilonis, T. dendrolimi, T. ostriniae, Lecanicillium lecanii, Beauveria bassiana, Metarhizium anisopliae, Neorautanenia mitis, Derris elliptica* (January *et al.*, 2018) [50], had shown good antibiotic effects through egg parasitic, larvicidal activity on *S incertulas, S inference* and *C. suppressalis* population (Baladhiya *et al.*, 2018; Upamanya *et al*., 2013; Yuan *et al.*, 2012) [13, 96, 99] and egg parasitoid activity on *C. polychrysus* populations (January *et al.*, 2018) [50]. (Table 3).

4.4 Control by Resistant Rice Cultivars

Widely used rice cultivars like Gontra Bidhan 3, MTU-2020, XR 99986 (29 P 38), IR 50 (Chavan and Patel, 2018a) [25], TKM 6, PTB 10, Su Yai 20, Mudgo, NDR-97, GAR 13, IR 22 (Chavan and Patel, 2018b) [26], TKM 6, KMD1, KMD2 (Ye *et al*., 2001) [98] DV 139, Taitung 16 (Das, 1976a) [34], W 1263, MTU 15 (Das, 1976b) [35] seem to be very effective against stem borer populations (Pongprasert, 1985) [72] (Table 2).

4.5 Control by Phoromone and Allomone: In recent days some chemicals are produced by female pest to attract males for mating, farmers also use those pheromones to attract males (Bhatt *et al.*, 2018) [16]. Sex pheromones like (Z)-9-hexadecenal, (Z)-11-hexadecenal (Cork *et al*., 2008) [30], Z-11-hexadecenyl acetate, Z11-16 Acetate, (Dang *et al.*, 2016) [32] (Z)-hexadec-11-enal (1), (Z)-octadec-13-enal (2), and (Z)-hexadec-9-enal (Liu *et al.*, 2020) [58] were very effective to attract the male and female which help in mass trapping and mating disruption of insects for management of stem borer (Rao *et al.*, 1994) [76] As a corollary allomone like extracts of resistant rice varieties like TKM 6 repel herbivore stem borer pests population and prevent them from feeding in the rice field (Pathak and. Khan, 1994) [69] (Table 3).

4.6 Mechanical and Cultural Control

Most popular mechanical and cultural techniques based on crop sanitation because most of deleterious rice insect pests or their eggs present at seedlings have considered as source of infestation (Zhu *et al.*, 2014) [101]. Mostly used crop sanitation technique are seed soaking with insecticide and fertilizer, clipping of leaves of rice plants at maximum tillering stage, seedling root dipping, removal, burn, plough of stubbles at ground, drain out water in infested paddy field, removal of alternate grassy and other weeds hosts from seedbed, paddy field and surrounding area shown very effective against different rice pests including stem borers (Bhatt *et al.*, 2018; Kunal *et al.*, 2020) [16, 57]. Cultivation of certain rice varieties like Pusa Basmati-1 near main crop can be used as trap crop to reduce damage to the main crop (Padmakumari *et al.*, 2017) [67]. Crop rotation with soyabin, pulse, potato oil seed in low land and cultivation of maize in upland area are also useful against different insect pests of rice (Breidenbach *et al*., 2017; Chen *et al*., 2018) [17, 28]. Even, uses of kerosene or electric light traps are very helpful against stem borers like other pest species (Bhatt *et al.*, 2018) [16].

4.7 Population Based Control: Several demographical models described age-specific (horizontal) and stage-specific (vertical) life-table of pest population to analyze changes in the measurement of several demographic parameters that help to determine survivorship type and also predict most vulnerable stage or stage having higher mortality rate (Dutta and Roy, 2016, 2018b; Mobarak *et al.*, 2020) [38, 62]. Developing of life tables for different rice pests under different agroclimatic condition and resistance factor are helpful for assessing population density and fluctuation in field conditions (Udayakumar *et al.*, 2016) [94]. In PSB, *S. inference*, approximate generation time (T_c) were found higher in alternative host maize than in sugarcane, whereas intrinsic rate of natural increase (r_m), finite rate of increase (λ), gross reproduction rate (GRR), net reproduction rate (NRR) were higher in alternate host sugarcane than in maize (Sedighi *et al.*, 2016) [85]. By analyzing the life table data of rice pests in different host and agro-climatic condition type–III survivorship obtained in *S. incertulas* (Dutta and Roy, 2018) [39], type IV exhibited by *C. suppressalis* (Easwaramoorthy and Nandagopal, 1986) [40] and *C. polychrysus* (Alghali, 1988) [8]. By studying population dynamics, first instar larva of *S. incertulas* (Mukunthan, 1989) [63], *C. suppressalis* (Koyama, 1977) [55] have identified most vulnerable stages. Density of arthropod predation and dispersal loss during the first instar larva appeared as limiting factor for *C. suppressalis* (Huang *et al.*, 2020) [46]. By identifying most vulnerable stages and population dynamics along with limiting factors of rice insect pest are very essential for the timely adoption of different management practices (Mobarak *et al.*, 2020; Roy, 2019, 2020, 2021) [62, 77, 78, 79].

Table 1: Bionomics and economic threshold level (ETL) of different stem borers.

Stem Borer	Life cycle Stages	Total life cycle	Most Infectious Stage and Damage	Symptom of Damage	Economic Threshold Level	Reference
Yellow Stem Borer *Scirphophaga incertulas*	Egg, Larvae (5-6 insters), Pupa and Adult	31–45 days	Internodal penetration by newly hatched larva	Dead Heart (DH), White Head (WH)	5–10% damaged tillers or DHs	Asghar *et al*., 2009; Bhatt *et al*., 2018; Chakraborty and Deb, 2008; Cork *et al*., 1998; Dutta and Roy, 2018; Hamsein *et al*., 2020; Jasrotia *et al*., 2019; Panigrahi and Rajamani, 2008 [11, 16, 21, 31, 39, 44, 51, 68].
Pink Stem Borer *Sesamia inference*	Egg, Larvae (6-8 insters), Pre pupa, pupa and Adult	35 - 57 days	Larvae feed on the epidermal layer of the leaf	DH, WH	5–10% damaged tillers	Baladhiya *et al*., 2018; Bhatt *et al*., 2018; Catling et al., 1978; Chaudhari *et al*., 2018; Jeevanandham *et al*., 2020; Singh and Kular, 2015 [13, 16, 19, 24, 52, 90].
Dark headed stem borer *Chilo suppressalis*	Egg, Larvae (4 insters), pupa and adult	35-60 days	Larva bore the growing points and central leaf fail to unfold	DH, WH	2-8% hill or damage tillers	Bhatt *et al*., 2018; Catling et al., 1978; Chakraborty and Deb, 2008; Chaudhari *et al*., 2018; Luo *et al*., 2016; Pathak and. Khan, 1994; Ueno *et al*., 2006 [16, 19, 24, 103, 69, 95].
Stripped Stem Borer *Chilo polychrysus*	Egg, Larvae (3 insters), pupa and adult	26–61 days	Larva bore inside the leaf sheath	DH, WH	5% DHs or 6% WHs	Bhatt et al., 2018; Islam and Karim, 1997; Pathak and. Khan, 1994; Way *et al*., 1991 [16, 49, 69, 97].

Table 2: Stem borer host range and most resistant cultivars of rice.

Stem Borer	Host range	Resistant Rice Cultivar	Pest Vulnerable Stage	Proposed Reference
Yellow Stem Borer *Scirphophaga incertulas*	Rice, *Echinochloa spp*., *Paniculum spp*., *Cyperus spp*., *Dactylis glomerata*, etc.	Gontra Bidhan 3, MTU-2020, XR 99986 (29 P 38), IR 50, NDR-97, GAR 13 and IR 22	Immature stages	Chavan and Patel, 2018a, 2018b; Chopra *et al*., 2017; Dutta and Roy, 2018 [25, 26, 39].
Pink stem borer *Sesamia inference*	Rice, wheat, maize, *Echinochloa spp*., *Cyperus spp*., *Eleusine indica*, *Paspalum scrobiculatum*, etc.	TKM 6, PTB 10, Su Yai 20, Mudgo, DV 139 and Taitung 16	Immature stages	Das, 1976a; Jeevanandham *et al*., 2020; Singh, 2012 [34, 52, 89].
Dark headed stem borer *Chilo suppressalis*	Rice, maize, pearl millet, sugarcane, sorghum, broad bean, water oat, *Vetiver zizanioides* and other grassy weeds	TKM 6, KMD1 and KMD2	First instar larvae	Bhatt *et al*., 2018; Liu *et al*., 2011; Ye *et al*., 2001 [16, 56, 76].
Stripped Stem Borer *Chilo polychrysus*	Rice, maize, sugarcane, kodo, finger millet, foxtail millet and other grassy weeds	W 1263, MTU 15 and IR 50	First instar larvae	Bhatt *et al*., 2018; Das, 1976b; Neupane, 1990; Pongprasert, 1985 [16, 35, 64, 72].

Table 3: Management strategies of different stem borers.

Stem Borer	Control Measures	Management Strategy	Reference
Yellow Stem Borer *Scirphophaga incertulas*	Acephate, Fipronil, Dursban (Chlorpyrifos), Convoy (Quinalphos), Carbofuran, Fipronil, Carbosulfan, etc.	Chemical	Hurali *et al*., 2020; Islam *et al*., 2013; Rahman *et al*., 2020 [47, 48, 74].
	Extract of Neem (*Azadirachta indica*), Tobacco (*Nicotina tobacum*) Karanja (*Pongamia glabra*), Neem oil, Mahogany (*Swietenia macrophylla*) oil, etc.	Botanicals	Islam *et al*., 2013; Majlish *et al*., 2015; Rahman *et al*., 2020 [47, 61, 74].
	Extract of *Trichogramma japonicum*	Biological	Upamanya *et al*., 2013[96].
	(Z)-9-hexadecenal, (Z)-11-hexadecenal	Pheromone	Cork *et al*., 2008; Rao *et al*., 1994 [30, 76].
Pink Stem Borer *Sesamia inference*	Fenvalrate, Thiamethoxam, Spinosad, Chlorantraniliprole, Carbofuran, etc.	Chemical	Baladhiya *et al*., 2018; Zhao *et al*., 2019 [13, 102].
	Isolates of *Euborellia stali* (Dohrn), *Beauveria bassian*, *Metarhizium anisopliae*, etc.	Biological	Baladhiya *et al*., 2018[13].
	Z-11-hexadecenyl acetate, Z11-16 Acetate,	Pheromone	Dang *et al*., 2016 [32].
Dark headed stem borer *Chilo suppressalis*	Carbofuran, Fipronil, Diazinon, Disulfoton Padan, TXH09, etc.	Chemical	Khan *et al*., 2020; Zhao *et al*., 2019 [53, 102].
	Extract of rice variety TKM-6, Pentadecanol TKM-6	Botanicals	Prakash *et al*., 2008 [73].
	Extract powder of *Trichogramma japonicum*, *T. chilonis*, *T. dendrolimi*, and *T. ostriniae*	Biological	Yuan *et al*., 2012 [99].
	Extracts of TKM6 and other resistant rice varieties	Allomone	Pathak and. Khan, 1994 [69].
	(Z)-hexadec-11-enal (1), (Z)-octadec-13-enal (2), and (Z)-hexadec-9-enal	Pheromone	Liu *et al*., 2020 [58].
Stripped Stem Borer *Chilo polychrysus*	Deltamethrin, Spinosad, Lambda-cyhalothrim, Emamectin-benzoate, Indoxacarb, Chlorpyrifos-ethyl, etc.	Chemical	Achiri *et al*., 2020 [1].
	Extract of *Neorautanenia mitis*, *Derris elliptica*, *Metarhizium anisopliae*, *Beauveria bassiana*	Biological	January *et al*., 2018 [50].
	Extracts of TKM6 and other resistant rice varieties	Allomone	Pathak and. Khan, 1994 [69].

5. Discussion

Rice is considered a dominant crop which grown in 59.35 lakh hectare areas (Adak *et al.*, 2020; Adhikari, 2005; Sinha and Mishra, 2013) [2, 4, 91]. Generally rice is grown in three different cropping seasons such as Aus (autumn rice), Aman (winter rice) and Boro (summer rice) (Adak *et al.*, 2020; Adhikari *et al.*, 2012; Chakraborty and Deb, 2008) [2, 5, 21]. But different biotic stresses are causing 33% production loss in West Bengal (Adhikari, 2005, 2004; Aryal *et al*., 2018) [3, 4, 10]. Among the biotic stresses, stem borers like pest like, *S. incertulas*, *S. inference*, *C. polychrysus*, *C. suppressalis*, appeared as a causative agent for maximum production damage either directly or indirectly (Dhaliwal *et al.*, 2010; Mobarak *et al.*, 2020) [37, 62]. These pests encompass their life stages mainly in rice and some non rice weeds found in and around rice field (Chakraborty and Deb, 2008; Dutta and Roy, 2018) [21, 39]. During the unfavorable condition, most of the stem borer species can pass through more profound physiological change that helps the stem borer to live for months in dormancy stage called diapauses (Srivastava *et al.*, 2003) [92]. Life stages and demographic parameters of this pest are greatly affected by host system and agroclimatic conditions (Dhaliwal *et al.*, 2010; Dutta and Roy, 2018; Mobarak *et al.*, 2020; Roy, 2019, 2020, 2021) [37, 39, 62, 77-79]. Agro-Ecosystem Analysis (AESA) estimated ETL of all steam borer was 5% Dead Hearts or 1 egg mass per square meter or 1 moth per square meter during Pre-tillering whereas 5% dead heart during Mid-tillering stage while 1 moth per square meter in panicle initiation period and 1 egg mass per square meter or 1 moth per square meter or 6% white ears in flowering stage (Asghar *et al*., 2009; Catling *et al*., 1978; Cork *et al*., 1998; Way *et al*., 1991) [11, 19, 31, 97].

Modern agriculture concerned with ecological pest management (EPM) as a part of integrated pest management (IPM) for ecofriendly and sustainable climate smart agriculture (CSA) of different economic crops (Aryal *et al*., 2018; Pedigo and Higley, 1992; Pedigo *et al*., 1986; Roy, 2019, 2020, 2021) [10, 70, 71, 77-79]. The basic information on pest ecology is necessary before deciding any strategy to combat with the pest (Chen *et al*., 2018; Roy, 2019, 2020) [28, 78, 79]. For controlling pests generally farmers use different synthetic pesticides against them (Aktar *et al*., 2009; Majlish *et al.*, 2015) [7, 61]. Similarly several botanicals are also very effective against stem borers (Majlish *et al.*, 2015; Shitiri *et al.*, 2014) [61, 87]. Several mechanical and cultural control strategies include mechanical synchronized planting, cultivation of certain rice varieties like pusa basmati-1 as trap crop, soaking sprouted seed in synthetic pesticide, seedling root dipping in pesticide and fertilizer, etc. (Breidenbach *et al*., 2017; Chen *et al*., 2018; Padmakumari *et al*., 2017) [17, 28, 67]. On the other hand, few sex pheromones and some allomones are very effective in mass trapping and mating disruption of insects (Cork *et al*., 2008; Dang *et al*., 2016; Rao *et al*., 1994) [30, 32, 76]. Recent days farmers used microbial pesticides derived from strains of *B. thuringiensis*, *B. bassiana* etc. impart good efficacy against major paddy pests (January *et al*., 2018; Upamanya *et al*., 2013) [50, 96]. In other instances, few rice cultivers like, Mahananda, IR-72, Gontra Bidhan 3, MTU-2020, GAR 13, IR 22, IR-50, KS-282, IRRI-6, KSK-282, DR-83, NDR-97, IR-36, Ratna, etc. have provided resistance against rice pest population growth and development (Chavan and Patel, 2018a, 2018b; Das, 1976a, 1976b) [25, 26, 34, 35].

Unfortunately, even today farmers rely on indiscriminate use of synthetic chemical insecticides against those pests which also targeted beneficial natural enemies of pest, pollinator resulting destabilizing of biodiversity in agroecosystems (Horgan *et al.*, 2016; Zhu *et al.*, 2020) [45, 100]. To overcome this constrains caused by rice pests researchers usually use several parameters like cost benefit ratio (CBR), ETL (Catling *et al*., 1978; Selvaraj *et al.*, 2012; Way *et al*., 1991) [19, 86, 97], population dynamics, enhancing use of green pesticides and cultural methods for appropriate management strategies for rice pests (Horgan *et al.*, 2016; Zhu *et al.*, 2020) [45, 100]. Thus population based ETL calculation and time series for time specific judicious management of the insect pests will obviously support sustainable management strategies of the rice pest and or other such pest species for better production or rice.

6. Conclusion

Modern agriculture includes climate smart pest management (CSPM) as a part of IPM by using ETs for ecofriendly and sustainable climate smart agriculture (CSA) towards more production of crops. The basic information on the biology of an insect pest is necessary before deciding any strategy to combat with the pest. There is a worldwide growing awareness for promoting environmentally benign sustainable agricultural practices. This review will also raise awareness of the value and potential of international efforts to develop ecologically sound pest management approaches including conservation of biodiversity. Even it will enhance sustainable management of pest for better cultivation of crops by using CSPM strategy under the arena of CSA for successful cultivation of rice in the near future.

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