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BIOECOLOGY AND MANAGEMENT OF MAJOR INSECT PESTS OF RICE IN WEST BENGAL

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ABSTRACT

West Bengal is considered a large producer state of rice in India with an output of nearly 55.48% of total crop production of Bengal. In West Bengal, rice has grown in three different cropping seasons such as Aus (autumn rice), Aman (winter rice) and Boro (summer rice), contributing about 20.69% to the total net State Domestic Product (SDP). Rice production in West Bengal hampered by many biotic stresses mostly by stem borers [*Scirphophaga incertulas* (Walker, 1863), *Sesamia inference* (Walker, 1856), *Chilo polychrysus* (Meyrick, 1932), *Chilo suppressalis* (Meyrick, 1863)] leaf folder [*Cnaphalocrocis medinalis* (Guenee, 1854)], plant hoppers [*Nilaparvata lugens* (Stal, 1854), *Sogatella furcifera* (Horvath, 1899)], leaf hoppers [*Nephotettix virescens* (Distant, 1908), *Nephotettix nigropictus* (Stal, 1870)], rice hispa [*Dicladispa armigera* (Olivier, 1808)], rice bugs [*Leptocorisa acuta* (Thunberg, 1783), *Leptocorisa oratorius* (Fabricius, 1794), *Brevennia rehi* (Lindinger, 1943)], gall midge [*Orseolia oryzae* (Wood-Mason, 1889)], etc. Demographic parameter has shown that rice pests are greatly affecting rice host either caused directly by creating dead heart (DH), hopperburn, onion leaf, silver shoot during different stages of harvesting or by indirectly transmitting grassy stunt virus (RGSV), rice ragged stunt virus (RRSV), rice tungro viruses (RTV), rice tungro bacilliform virus (RTBV) etc. resulting 9.5% production loss. For minimize the infestation farmers use different rice varieties which provide resistance effect in pest population. For controlling rice pest population farmers mostly use chemical insecticide [e.g. fipronil, acephate, fipronil, monocrotophos] which exhibit good results against rice pests. Beside those other techniques including using biological and biochemical pesticides [neem oil, karanj oil, mahua oil, conidial suspension of *M. anisopliae*], pheromones [(Z)-11-hexadecinal, (Z)-9-hexadecenal], allomones [5: 1 mixture of 2-(E)-octenyl acetate and octanol 3-octenal], cultutal methods [synchronized planting, using of trap crop etc.] are effective for controlling rice pests. The population ecology based sustainable management of such pest species will support E^3 strategy [Ecosystem service-based ecological engineering for ecological pest management (ESS-EE-EPM)] of pest management for successful cultivation of rice in the near future.

Key words: *Oryza sativa*, state domestic product (SDP), West Bengal biotic stresses, sustainable management, E^3 strategy, chemical, pests, status, cultural, biopesticides, biological resistant variety, pheromones, population based control

Rice (*Oryza sativa* L., Gramineae or Poaceae, 2n=24) continues to remain as the staple food of West Bengal by contributing approximately 55.48% of total crop production (Adhikari et al., 2012; Bag et al., 2011; Dey et al., 2005). Several limiting factors such as flood, pest infestation, damage by animal and human activity causing yield loss thereby narrow down the profit of Bengal farmer (Dutta and Roy, 2022; Bag et al., 2011). Among them insect pests have appeared as the most important limiting factors during pre- and post-harvest stage of rice cultivation (Arora et al., 2019; Adhikari et al., 2019). For controlling rice insect pest in Bengal, farmers have been most frequently using synthetic pesticides in broad-spectrum which shown good efficacy against herbivorous insect pests (Adhikari et al., 2019; Tigga et al., 2018). Besides that, using of biochemical pesticides, biological agents, pheromone trap, repallent allomone, cultural strategies and 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 also shown good result for controlling rice insect pests (Sankar and Rani, 2018; Gunawardena and Bandumathie, 1993; Padhan and Raghuraman, 2018). All of these management processes have imparted negative impact also (Chatterjee et al., 2008). Sometime pest polulation create resistance against applied pesticide and also these pesticide tagets benifitial faunal biodiversity (pollinators, natural enemy of pest etc.) which create distabilizing agro ecosystem (Keary, 2023; Roy, 2020, 2021, 2022). Beside it has observed that all of rice pest management techniques did not consider economic threshold levels (ETLs) limit for pest that create ecological imbalance (Carvalho, 2017; Mobarak et al., 2020). These result into secondary pest outbreak, pest resurgence, and emergence of new pest biotypes, distabilized prey (rice pest)-predator (natural enemy of rice pest) stability, which ultimately leads regulatory complications with several constrains and limitations on the agro ecosystem (Dutta and Roy, 2016; Kakde and Patel, 2018; Kakde et al., 2014; Jeevanandham et al., 2020; Chávez et al., 2018; Roy, 2020, 2021). Therefore, this study emphasis that the life cycle of major rice pests, their active and passive infestation and their management that will very helpful to point out a possible scope for sustainable ecological management towards climate smart pest management (CSPM) through supporting E^3 strategy [Ecosystem service-based Ecological engineering for Ecological pest management (ESS-EE-EPM)] of pest management for successful cultivation of rice crop in the near future.

Status of cultivation

Agriculture is the leading occupation of West Bengal and rice is the state's principal food crop (Chatterjee et al., 2008; Adhikari et al., 2012). Rice cultivation in West Bengal has occurred in diversified ecosystems such as irrigated, upland, rainfed low land, semi deep water and deep water as well as coastal saline regions in three different cropping seasons, [Aus (autumn rice), Aman (winter rice) and Boro (summer rice)] (Dhaliwal et al., 2010; Azgar and Hembram, 2018; Aryal et al., 2018). Rice was cultivated 61% of the total geographical area in West Bengal, contributing about 20.69% of State Domestic Product (Adak et al., 2020). Rice in West Bengal generally cultivated in three different seasons Boro, Aus and Aman crop season (Dutta and Roy, 2022; Bag et al., 2011). Six different agro-climatic zones (Northern Hill Zone, Terai-Teesta Alluvial Zone, Gangetic Alluvial Zone, Red and Laterite Zone, Vindhya Alluvial Zone, Coastal Salaine Zone) of West Bengal is a producer of high yielding (Annada, Jamini, Bhupen, IR 36, IR 64, and IR 22 etc.), traditional or local (Bhadoi, Kabiraj Sal, and Shatia etc.), and aromatic rice varieties [Basmati, Badsabhog, Gobindabhog, Tulaipanji, etc.] (Bag et al., 2011; Mandal et al., 2022; Chatterjee et al., 2008; Dutta and Roy, 2022). This rice production was mostly hampered by insect pest infestation, accounted 7.37% of total rice production (Ghosh et al., 2015; Aryal et al., 2018) (Table 1, 2).

Status of rice insect pests

At the present agricultural scenario, loss in production of rice crop is due to a variety of major insect pest infestation (Chakraborty and Deb, 2012; Ghule et al., 2008). Generally, the crop loss at the farm level during pre and post harvest level occurred by major insect pests like stem borers, gall midge, plant hoppers, leaf folders, rice hispa, and rice bug etc. (Sarkar et al., 2016; Chakraborty and Deb, 2012) (Table 1, 2).

A. Stem borers

The rice production in West Bengal mostly hamperd by infestation causing Lepidopteran stem borer species which include yellow stem borer (YSB), *Scirphophaga incertulas* (Walker, 1863) (Lepidoptera: Pyralidae), pink stem borer (PSB), *Sesamia inference* **(**Walker, 1856**)** (Lepidoptera: Pyralidae), stripped stem borer (SSB) *Chilo suppressalis* (Meyrick, 1863) (Lepidoptera: Pyralidae), dark headed stem borer (DHSB) *Chilo polychrysus* (Meyrick, 1932) (Lepidoptera: Pyralidae), (Shivasharanappa et al., 2010; Dutta and Roy, 2022; Chakraborty, 2012). *Scirphophaga incertulas* (Walker) encompasses egg, 5-6 instars larvae, pre- pupa, pupa and adult during their life cycle (Hamsein et al., 2020; Dutta and Roy, 2018b). *Sesamia inference* **(**Walker) encompasses egg, 6-8 instars larvae, pre pupa, pupa and adult during their life cycle (Baladhiya et al., 2018; Jeevanandham et al., 2020). *Chilo suppressalis* (Meyrick) has passed egg, 4 instars larvae, pupa to become full grown adult (Pathak and. Khan, 1994; Dutta and Roy, 2022). *Chilo polychrysus* (Meyrick) also shown same development pattern except 3 instars larva has shown instead of 4 instars of larva (Bhatt et al., 2018; Luo et al., 2016). Damage caused by stem borer has encounted due to internodal penetration by newly hatched larva during vegetative phase specially in booting or flowering stage which remain inside or behind leaf sheath in groups and feed on the epidermal layer of leaf sheath formation of oblong holes in parallel rows in the unfolded leaves as a result central leaf turns brownish, a condition known as ‘Dead Heart’ (DH) (Bhatt et al., 2018; Pathak and Khan, 1994). When infestation was severe resulting folding of older rice

Table 1. Biological parameters and host range of different rice pests

Rice pest	Common name and Scientific name	Stages in life cycle	Parameters of life cycle	Period	Reference
Stem borer	Yellow stem borer *Scirphophaga incertulas*	Egg, larvae (5-6 instars), pre-pupa, pupa and adult	Oviposition period	26.0 hours	Hamsein et al., 2020; Dutta and Roy, 2018b; 2022.
			Larval period	20-40 days	
			Pre-pupal period	1-2 days	
			Pupal period	6-12 days	
			Number of days in life cycle	52–64 days	
			Number of generation each year	5-8	
	Pink stem borer *Sesamia inference*	Egg, larvae (6-8 instars), pre pupa, pupa and adult	Oviposition period	2 days	Baladhiya et al., 2018; Jeevanandham et al., 2020; Dutta and Roy, 2022.
			Larval period	21-39 days	
			Pre-Pupal period	1-2 days	
			Pupal period	8-14 days	
			Number of days in life cycle	45-57 days	
			Number of generation each year	4-5	
	Stripped stem borer *Chilo suppressalis*	Egg, larvae (4 instars), pupa and adult	Oviposition period	5 days	Pathak and Khan, 1994; Dutta and Roy, 2022; Bhatt et al., 2018.
			Larval period	23-36 days	
			Pupal period	7-8 days	
			Number of days in life cycle	35-57 days	
			Number of generation each year	6	
	Dark headed stem borer *Chilo polychrysus*	Egg, larvae (3 instars), pupa and adult	Oviposition period	3 days	Dutta and Roy, 2022; Bhatt et al., 2018; Luo et al., 2016.
			Larval period	23-39 days	
			Pupal period	7 days	
			Number of days in life cycle	35-60 days	
			Number of generation each year	2	
Leaf folder	Leaf folder *Cnaphalocrocis medinalis*	Egg, larvae (5-6 instars), pupa, adult	Oviposition period	3 days	Bhatt et al., 2018; Gangwar, 2015.
			Larval period	14-23 days	
			Pupal period	6-10 days	
			Number of days in life cycle	15-28 days	
			Number of generation each year	11	
Planthoppers	Brown planthopper *Nilaparvata lug*ens	Egg, Five nymphal stage and Adult	Oviposition period	10 days	Catindig et al., 2009; Bottrell and Schoenly, 2012.
			Nymphal period	18-32 days	
			Number of days in life cycle	25 to 44 days	
			Number of generation each year	12-13	
	White backed planthopper *Sogatella furcifera*	Egg, five nymphal instar, adult	Oviposition period	2 days	Kaur et al., 2015; Kumar, 2019.
			Nymphal period	15-28 days	
			Number of days in life cycle	20-31 days	
			Number of generation each year	5-6	

(contd.)

(Table 1 contd.)

Leafhopper	Green leafhopper *Nephotettix virescens* and *Nephotettix nigropictus*	Egg, five instars nymph and adult	Oviposition period	9-14 days	Bunawan et al., 2014; Bhatt et al., 2018; Dey, 2016.
			Nymphal period	12-18 days	
			Number of days in life cycle	21-35 days	
			Number of generation each year	11	
Rice hispa	Rice hispa *Dicladispa armigera*	Egg, four instars larva, pupa. adult	Oviposition period	12 days	Iqbal et al., 2015, Bhattacharjee and Ray, 2017.
			Larval period	11-14 days	
			Pupal period	7-8 days	
			Number of days in life cycle	18-36 days	
			Number of generation each year	6	
Rice bug	Gundhi bug *Leptocorisa oratorius*	Egg, five nymphal stage and adult	Oviposition period	12 days	Khare and Prakash, 2020; Arora et al., 2019.
			Nymphal period	24-36 days	
			Number of days in life cycle	24-36 days	
			Number of generation each year	2-5	
	Earhead bug *Leptocorisa acuta*	Egg, Six nymphal stage and Adult	Oviposition period	5 days	Dutta and Roy, 2016, 2018a; Pathak and Khan, 1994; Bhatt et al., 2018.
			Nymphal period	22-24 days	
			Number of days in life cycle	30 to 60 days	
			Number of generation each year	4-5	
	Rice mealy bug *Brevennia rehi*	Egg, Four nymphal instars and Adult	Oviposition period	26 hours	Bhatt et al., 2018; Pathak and Khan, 1994.
			Nymphal period	14-30 days	
			Number of days in life cycle	17-37 days	
			Number of generation each year	12-13	
Gall midge	Rice gall midge *Orseolia oryzae*	Egg (3 instar), larva, pupa and adult	Oviposition period	2 days	Ogah and Nwilene, 2017; Bhatt et al., 2018;Ouattara et al., 2020.
			Larval period	9-26 days	
			Pupal period	2-8 days	
			Number of days in life cycle	15-34 days	
			Number of generation each year	4-5	

Table 2. Infestation parameters of rice pests

Rice pest	Name of pest	Most infectious stage	Economic threshold level	Nature of damage	Symptom of damage	Reference
Stem borer	Yellow stem borer *Scirphophaga incertulas*	Larva	5–10% damaged tillers	Due to larval boring and feeding activity inside leaf sheath resulting in yellowing of leaves.	Dead Heart (DH)	Bhatt et al., 2018; Pathak and Khan, 1994; Baladhiya et al., 2018; Asghar et al., 2009; Cork et al., 1998.
	Pink stem borer *Sesamia inference*	Larva	1.9-3.0% WHs			
	Stripped stem borer *Chilo suppressalis*	Larva	2-8% hill or damage tillers	On severe condition folding of older rice leaves became drying off and turns whitish in colour.	White Head (WH)	
	Dark headed stem borer *Chilo polychrysus*	Larva	5% DHs			
Leaf folder	Leaf folder *Cnaphalocrocis medinalis*	Larva	3% folded leaves or 0.2-5 adult per hill	Scrapping the green mesophyll tissue affecting on photo-system II activity in photophosphorylation process resulting in scorching and drying of the leaves affecting in plant growth and reduce yield.	Leaf folding	Padmavathi et al., 2012; Pathak and Khan, 1994; Bhatt et al., 2018; Asghar et al., 2009.
Plant-hoppers	Brown planthopper *Nilaparvata luge*ns	Nymphs and adults	3-8 nymphs/hill	Sucking phloem sap from stem and leaf sheath resulting yellowing of leaves and by ovipositional activity causing damage to plant tissue. On severe infestation results complete drying of the plants. Transmit Rice grassy stunt virus (RGSV) and rice ragged stunt virus (RRSV).	Hopperburn, Grassy Stunt (GS), Ragged Stunt (RS), Wilte Stunt (WS).and Rice Yellowing Syndrome (RYS)	Catindig et al., 2009; Bhatt et al., 2018; Kaur et al., 2015; Bottrell and Schoenly, 2012; Matharu and Tanwar, 2020.
	White backed planthopper *Sogatella furcifera*	Nymphs and adults	4% hopperburn or 10-20 hoppers/hill	Sucking phloem sap from stem and leaf sheath resulting yellowing of leaves and by ovipositional activity causing damage to plant tissue and encourages the growth of sooty mould eg. *Cladosporium*sp and*Dematium* sp. On severe infestation results complete drying of the plants. Transmit Southern rice black-streaked dwarf virus (SRBSDV).	Hopperburn, Southern rice black-streaked dwarf disease (SRBSDD)	Catindig et al., 2009; Kaur et al., 2015; Bhatt et al., 2018.
Leaf-hopper	Green leafhopper *Nephotettix virescens* and *Nephotettix nigropictus*	Nymphs and adults	2-20 insects per hill	Suck up sap from vascular vessels and by ovipositional activity damage cortex and epidermal layer of leaf resulting yellowing plant, drying up of panicle. Transmit Rice Tungro Viruses (RTV), Rice Tungro Bacilliform Virus (RTBV), Rice Tungro Spherical Virus (RTSV), Rice Dwarf Virus (RDV), Rice Waika Virus (RWV) along with bacterial and fungal infection.	Milder Tungro Symptoms (MTS), Mild Stunting Symptoms (MSS), Dwarf Syndrome (DS), Yellow-Orange Leaf Symptom (YOLS)	Pathak and Khan, 1994; Dey, 2016; Sabale et al., 2010.

(contd.)

(Table 2 contd.)

Rice hispa	Rice hispa *Dicladispa armigera*	Grubs and adults	2 damaged leaves/plant or 1-2 adults/hill	By feeding upon the chlorophyll content of leaves and also through scrapping the upper and lower surfaces of leaves resulting appearance of blisters and blotches or burned appearance on surface of leaves with parallel white lines on the leaf surface.	Leaf folding	Iqbal et al., 2015; Rahaman et al., 2020.
	Gundhi bug *Leptocorisa oratorius*	Nymph and adult	2 bugs/ m2 or 2 adults/ hill	Through piercing and sucking mouth part suck up the milky juice of the developing rice grains resulting partially filled grains. Severe infestation resulting chaffy and empty grains remain small in size. Passively transmit *Sarocladium oryzae* and *S. attenuatum* (fungi).	Panicles discoloration, Sooty Mould, Sheath Rot	Dutta and Roy, 2016; Khare and Prakash, 2020; Bhatt et al., 2018; Arora et al., 2019; Dutta et al., 2020, 2021; Bhatt et al., 2018.
Rice hug	Earhead bug *Leptocorisa acuta*	Nymph and adult	0.5-1 individuals (adult and nymph)/ hill			
	Rice mealy bugs *Brevennia rehi*	Nymphs and adults	3-5% affected tillers	Sucking the sap from stems and leaf sheaths resulting in leaves become yellowish, dried off and curled, also affects the panicle-bearing capacity of plant. Act as a vector for chlorotic streak virus and *Sarocladium oryzae*	Stunting and wiltingplant, Sheath Rot Disease	Bhatt et al., 2018; Pathak and Khan, 1994; Rath et al., 2020b.
Gall midge	Rice gall midge *Orseolia oryzae*	Larval	5-10% onion shoots or silver shoot	Feeding secretes a chemical known as cecidogen from its saliva which affecting nutrient supply and resulting central leaf elongation and tubular gall-like structure is formed. Larval feeding on the meristematic tissue of terminal and auxiliary shoot apices resulting in gall formation.	Onion leaf Silver shoot	Ogah and Nwilene, 2017; Bhatt et al., 2018; Kumari et al., 2020.

leaves longitudinally with the abaxial surface inside the folds, while younger instars partially rolled the leaf edges and folds were made along the middle portion of upper leaves with drying off central leaf which turn into whitish in colour and condition is known as 'White Ears or White Head' (WH) (Baladhiya et al., 2018). Agrosystem analysis estimated that economic threshold level was 5 to 10% damaged tillers for *Scirphophaga incertulas* (Walker) and 1.9-3.0% white heads for *Sesamia inference* (Walker) whereas 2-8% hill or damage tillers for *Chilo suppressalis* (Meyrick) while 5% dead hearts recorded for *Chilo polychrysus* (Meyrick) (Asghar et al., 2009; Cork et al., 1998). Stem borers activity mostly has been recorded mostly on rice, beside that they also aggregate on wild grasses like *Paniculum*s sp., *Echinochloa* sp., *Cyperus* sp., *Dactylis* sp., *Scirpus* sp., *Saccharum* sp. etc. grown in and around crop fields (Bhatt et al., 2018; Dutta and Roy, 2018b; Jeevanandham et al., 2020).

B. Leaf folder

Rice leaf folder, *Cnaphalocrocis medinalis* (Guenee, 1854) (Lepidoptera: Pyralidae) were predominant defoliator pests during nursery to harvest (Bhatt et al., 2018). It encompasses egg, 5-6 larval instars, pupa and adult (Gangwar, 2015). Damage generally done due to voracious feeding by fourth and fifth instar inside leaf by scrapping the green mesophyll tissue of upper epidermis but the lower epidermis becomes dry and falls off and longitudinal folding of leaves by stitching the leaf margins with the help of salivary secretions (Padmavathi et al., 2012). Within the folded leaves reduction in chlorophyll content occur, influencing on photo-system II activity in photophosphorylation process in photosynthesis resulting membranous patches resulting in scorching and drying of the leaves which ultimately affecting in plant growth and reduce yield (Pathak and Khan, 1994). Beside that faecal matter of insect inside the folded leaf can cause development of fungal and bacterial infections (Bhatt et al., 2018). Researches have shown that economic threshold level which are 3% folded leaves or 0.2-5 adult per hill (Asghar et al., 2009). This deleterious leaf folder mainly infested rice with that they aggregated on plant like maize, *Panicum decompositum*, *Leersia hexandra*, *Echinochloa crusgalli*, *Leptochloa chinensis*, *Isachne dispar*, *Eleusine coracana*, and *Pennisetum typhoides* (Hurali et al., 2020; Asghar et al., 2009).

C. Planthopper

Herbivorous sap-feeding homopterans brown plant hopper (BPH) *Nilaparvata lugens* (Stal, 1854) (Hemiptera: Delphacidae) and white backed plant hopper (WBPH) *Sogatella furcifera* (Horvath, 1899) (Hemiptera: Delphacidae) have posed a serious threat in summer Amon rice of Bengal (Matharu and Tanwar, 2020). Generally, two morphological types of plant hopper, macropterous and brachypterous have noticed in agrosystem (Catindig et al., 2009). Both morphological types of *N. lugens* (Stal) and *S. furcifera* (Horvath) encompass egg, six nymphal stages and adult (Bottrell and Schoenly, 2012). Damages caused by nymphs and adults of *N. lugens* (Stal.) and *S. furcifera* (Horvath) actively in growing plants during tillering stage and flowering stage by sucking phloem sap from stem and leaf sheath resulting yellowing of leaves and by ovipositional activity during booting and heading stages causing damage to plant tissue (Catindig et al., 2009; Bhatt et al., 2018). Severe infestation results complete drying of the plants, known as hopperburn (Kaur et al., 2015; Catindig et al., 2009). Feeding punctures and lacerations caused by ovipositor predispose of white-backed planthopper on plants to pathogenic organisms and honey dew excretion encourages the growth of sooty mould such as *Cladosporium* sp. and *Dematium* sp. (Kaur et al., 2015). Passively *N. lugens* (Stal.) can damage by transmitting Rice grassy stunt virus (RGSV) and rice ragged stunt virus (RRSV) result in rice yellowing syndrome (RYS) in rice (Bottrell and Schoenly, 2012). Similarly, *S. furcifera* (Horvath) act as an important vector of fiji virus, Southern rice black-streaked dwarf virus (SRBSDV) causing of Southern rice black-streaked dwarf disease (Bhatt et al., 2018). ETLs have encounted for brown planthopper 3-8 nymphs/hill (Matharu and Tanwar, 2020) whereas 4% hopperburn or 10-20 hoppers/ hill have recordedfor white-backed planthopper (Bhatt et al., 2018). Generally, the rice is considering the best suitable host system for planthopper development but they had also aggregate on a weed *Leersia* sp., *Digitaria* sp., *Echinochloa* sp., *Isachne globosa, Poa annua, Poa repens* (Bhatt et al., 2018; Matharu and Tanwar, 2020).

D. Leafhopper

The rice green leafhoppers (GLHs) *Nephotettix virescens* (Distant, 1908) and *Nephotettix nigropictus* (Stal, 1870) (Hemiptera: Cicadellidae) have considered another devastating herbivorous pest of Kharif crop season (Bhatt et al., 2018). During life cycle it encompasses Egg, five instars nymph and adult stages (Dey, 2016). Damage mainly cause by either directly with their needle shaped piercing and sucking mouth part sucking the sap and plugging the vascular bundles (xylem and phloem) with their feeding stylet sheaths results in wilting and pieces of tissue pushed into these vessels during exploratory feeding and oviposition or indirectly by transmitting virus diseases during feeding caused by Rice Tungro Viruses (RTV), Rice Tungro Bacilliform Virus (RTBV), Rice Tungro Spherical Virus (RTSV), Rice Waika Virus (RWV), Rice dwarf virus (RDV) responsible for Milder Tungro symptoms, Mild stunting Symptoms Wilting, Dwarf syndrome, Transitory yellowing syndrome, Yellow dwarf syndrome and Yellow-orange leaf symptom and also transmit fungal and bacterial infection responsible for Sooty Moulds in infected plant (Pathak and Khan, 1994; Dey, 2016). Economic threshold level of leafhopper has found 10± 9 insects per hill (Sabale et al., 2010). Generally, the rice is considering the best suitable host system for planthopper development but they had also aggregate on *Leersia* sp., *Digitaria* sp., *Echinochloa* sp., *Isachne globosa, Poa annua,* and *Panicum repens* etc. (Sarao and Bentur, 2018; Dey, 2016).

E. Rice hispa

The rice hispa or spiny beetle, *Dicladispa armigera* (Olivier, 1808) (Coleoptera: Chrysomelidae), has occupied a status of major pest of boro rice cultivation (Bhattacharjee and Ray, 2017). This pest encompasses egg, four instars larva or grubs, pupa and adult during their development (Iqbal et al., 2015).During vegetative stage of plant, the grubs feed upon the chlorophyll content of leaves and leaves became dry and give rise to blisters or blotches (Bhattacharjee and Ray, 2017). Adults also damaged through scrapping the upper and lower surfaces of leaves result in white streaks parallel to the midrib of leaves (Iqbal et al., 2015). During infestation photosynthetic activity of the leaves gets affected and leaves became dry and give rise blisters and blotches or burned appearance on surface of leaves with parallel white lines on the leaf surface (Rahaman et al., 2020). It has reported that ETL of this delitorious pest recorded 2 damaged leaves/plant or 1-2 adults/hill (Iqbal et al., 2015). This notorious pest also aggregated on *Andropogon gayanus*, *Sorghum halepense*, *Imperata cylindrica* and *Themeda anathera* (Rahaman et al., 2020).

F. Rice bug

The rice bugs have considered prevalent major pests for rainfed wetland or upland rice belong to *Leptocorisa* sp., *Brevennia rehi* (Lindinger, 1943) (Rath et al., 2020a, 2020b). *Leptocorisa acuta* (Thunberg, 1783) (Hemiptera: Alydidae) and *Leptocorisa oratorius* (Fabricius, 1794) (Hemiptera: Alydidae) are known as Gundhi Bug (GB) due to releasing of characteristic graceless, bothersome, incursive odour on inciting caused by chemicals released from the bug's abdominal glands (Dutta et al., 2020). Rice Mealy Bugs (RMB), *Brevennia rehi* (Lindinger, 1943) (Hemiptera: Pseudococcidae) are plant-sucking, sporadic insect pest of rainfed rice (Bhatt et al., 2018). Life cycle of *Leptocorisa oratorius* (Fabricius) include egg, five nymphal stage and adult (Khare and Prakash, 2020; Arora et al., 2019) but *Leptocorisa acuta* (Thunberg) also shown developmental stages except they have six nymphal stages instead of five stages (Dutta and Roy, 2016, 2018a). *Brevennia rehi* (Lindinger, 1943) has encompassed egg, four nymphal instars and adult during their development (Bhatt et al., 2018; Pathak and Khan, 1994). Damage occurs generally during milk stage to dough stageby nymphs and adults of *L. acuta* (Thunberg) and *L. oratorius* (Fabricius) through piercing and sucking mouth part suck up the milky juice of the developing rice grains resulting partially filled grains (Dutta and Roy, 2016, Khare and Prakash, 2020; Dutta et al., 2020). Severe infestation resulting chaffy and empty grains remain small in size (Bhatt et al., 2018). The *L. acuta* (Thunberg) and *L. oratorius* (Fabricius) passively transmit *Sarocladium oryzae* and *S. attenuatum*, the cause of sheath rot disease which results in damaging of the panicle of the rice plant and infected plant may not produce rice grains (Arora et al., 2019). Economic threshold level has encounted for *L. acuta* (Thunberg) 2 bugs/ m^2 or 2 adults/ hill (Dutta et al., 2020) whereas that level for *L. oratorius* was 0.5-1 individuals (adult and nymph)/ hill (Bhatt et al., 2018). Similarly, damages occur by *B. rehi* (Lindinger) by both nymphs and adults feed by sucking the sap from stems and leaf sheaths resulting leaves become yellowish, dried off, and curled (Bhatt et al., 2018). The infestation also affects the panicle-bearing capacity of plant and produces chaffy grains and also stunting and wilting infected plant leading growth and development of the affected plant with that infested fields show isolated patches of stunted plants (Rath et al., 2020b). Presence of this bug well marked by protruding white waxy fluff between the leaf sheath and the stem and mealybug-infested grains have not developed properly, having bitter taste with spoil, flavour (Pathak and Khan, 1994). Passively this insect pest is also known to transmit chlorotic streak virus and *Sarocladium oryzae* responsible for sheath rot disease (Bhatt et al., 2018). Economic threshold level of *B. rehi* (Lindinger) has estimated 3-5% affected tillers (Rath et al., 2020b). *L. acuta* (Thunberg), *L. oratorius* (Fabricius) and *B. rehi*

(Lindinger) are generally aggregated on rice host (*Oryza sativa*) beside that they also aggregated on non rice hosts also like, *Echinochloa glabrescens*, *Paspalidium flavidum, Paspalum scrobiculatum*, *Echinochloa crusgalli, Echinochloa colona*, *Paniculum* spp. *Cyperus* sp. (Dutta and Roy, 2018a; Rath et al., 2020b).

G. Gall midge

Asian rice gall midge, *Orseolia oryzae* (Wood-Mason, 1889) (Cecidomyiidae: Diptera) were considered as one of the major destructive pests of lowland to upland rice (Nacro et al., 1996). Development of *O. oryzae* (Wood-Mason) involves egg, three larval instars, pupa and adult completed in 15-34 days (Ogah and Nwilene, 2017). Gravid females are laid tubular or rod-shaped eggs in vicinity of plant below or above ligules, on leaf blade, central whorl, standing water near the plant (Mathur and Rajamani, 1984).Infestation by *O. oryzae* (Wood-Mason)has seen from nursery to the tillering stage (Bhatt et al., 2018). Larvae enter the shoot apex and larval feeding secretes a chemical known as cecidogen from its saliva which affecting nutrient supply and resulting central leaf elongation and tubular gall-like structure is formed, resembles as "onion leaf"' beside that due to larval feeding on the meristematic tissue of terminal and auxiliary shoot apices resulting in gall formation the characteristic symptom is known as "silver shoot" due to the shiny appearance of the leaf (Ogah and Nwilene, 2017). Through mathametical model that ETLs are 5-10% onion shoots or silver shoot (Bhatt et al., 2018; Kumari et al., 2020). Rice *Oryza sativa* has considered as most favourable host but this pest also aggregated in *Cynodon dactylon, Echinochloa colona, Paspalum scrobiculatum, Brachiaria mutica, Heteropogon contortus, Paspalidium geminatum* and *Leersia hexandra* (Bhatt et al., 2018).

H. Other pests

There are other insect pests of rice in West Bengal having regional significance such as army worm *Mythimna separate* (Walker), grasshoppers *Hieroglyphus banian* (Fabricius), white stem borer *Scirpophaga innotata* (Walker) and rice thrips *Stenchaetothrips biformis* (Bagnall), etc. (Chatterjee et al., 2008).

Management strategies (Table 3)

In this modern era with increasing human population there is a need to increase rice production per unit of land through sustainable management strategies (Dutta et al., 2021; Chávez et al., 2018). 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 (Roy, 2019a, 2019b; Kunal et al., 2020).

A. Chemical control

Most popular method used by farmers for controlling insect rice pest was through using synthetic chemical pesticide (Roy, 2019a, 2019b). Application of aquous or oily spray of fenvalrate, acephate, quinalphos, cartap hydrochloride, flubendiamide, carbofuran, carbosulfan, chlorantraniliprole, fipronil, thiamethoxam, chlorpyrifos, spinosad, and N-((2,6-dimethyl-4-(heptafluoropropyl-2-yl)phenyl) carbamoyl)-2,6-difluorobenzamide has shown best efficacy against adult and larva of rice leaf folder, gall midge, planthopper, leafhopper, gandhi bug, mealybug and stem borers (Shyamrao and Raghuraman, 2019; Dutta and Roy, 2022; Zhao et al., 2019; Baladhiya et al., 2018). Application of soil granular formulation of diazinon, propaphos, endrin chlorfenvinphos, disulfoton, padan, deltamethrin, propenphos, propenphos, chlopyriphos, monocrotophos, imidacloprid, buprofezin, cycloxaprid, pymetrozine, sulfoxaflor, indoxacarb, flonicamid, malathion, dimethoate, phosphamidon, dinotefurain, chlorpyriphos, cypermethrin, lindane, triazophos, spinosad, rynaxypyr, and endosulfan during sedling plantation have shown good result for managing adult and larval incidence caused by major insect pests (Dutta and Roy, 2022; Zhao et al., 2019; Achiri et al., 2020; Matharu and Tanwar, 2020; Hurali et al., 2020; Luo et al., 2023; Adhikari et al., 2019; Bhattacharjee and Ray, 2017; Gupta et al., 2019; Kumari et al., 2020; Adhikari et al., 2019). Monocrotophos, imidacloprid, and triazophos were most economical on basis of cost benefit ratio (CBR) (Tigga et al., 2018; Adhikari et al., 2019).

B. Cultural control

For controlling deleterious rice pests, popular mechanical and cultural techniques used by farmers was based on crop sanitation because in most of casees it has observed that source of infestation occurred by egg, larva and adult of phytophagous rice insect pests that persist during seedlings (Ayelo et al., 2021). Another popular method was based on plant quarantine technique which includes raising crop nurseries away from light source avoids the early infestation have done by rice insect pests (Seleiman et al., 2021). Most commonly used crop sanitation technique are seed soaking with fertilizer along with insecticide, clipping

Table 3. Management strategies for rice pests

Rice pest	Common name and scientific name	Management agents	Management strategies	References
Stem borer	Yellow stem borer *Scirphophaga incertulas*	Carbofuran, carbosulfan, fipronil, acephate, fipronil, chlorpyrifos, quinalphos, flubendiamide.	Chemical	Shyamrao and Raghuraman, 2019; Dutta and Roy, 2022
		Leaf extract of neem (*Azadirachta indica*), tobacco (*Nicotina tobacum*), Karanja (*Pongamia glabra*), bishkatali (*Polygonum hydropiper*), lantana (*Lantana camara*) and neem oil, mahogany (*Swietenia macrophylla*) oil, etc.	Botanicals	Shyamrao and Raghuraman, 2019.
		Extract of *Trichogramma japonicum*.	Biological	Dutta and Roy , 2022.
	Pink stem borer *Sesamia inference*	Fenvalrate, thiamethoxam, spinosad, chlorantraniliprole, carbofuran.	Chemical	Baladhiya et al., 2018; Zhao et al., 2019.
		Isolates of earwig *Euborellia stali* (Dohrn), Bt protoxin Cry1ca, Isolates of *Beauveria bassiana,*NBAII- Bb-1, 4, 6, 8, 11, 15, 39 and 59 isolates.	Biological	Baladhiya et al., 2018.
	Dark headed stem borer *Chilo suppressalis*	Fipronil, carbofuran, diazinon, disulfoton Padan, TXH09 [N- ((2,6-dimethyl-4-(heptafluoropropyl-2-yl)phenyl)carbamoyl)-2,6- difluorobenzamide]	Chemical	Zhao et al., 2019; Khan et al., 2020.
		Extract of rice variety TKM-6, Pentadecanol TKM-6	Botanicals	Prakash et al., 2008.
		Extract powder of *Trichogramma japonicum, Trichogramma chilonis, T. dendrolimi*, and *T. ostriniae*	Biological	Hajjar et al., 2023.
	Stripped stem borer *Chilo polychrysus*	Spinosad, deltamethrin, lambda-cyhalothrim, emamectin-benzoate, indoxacarb, chlorpyrifos-ethyl, chlorantraniliprole, novaluron	Chemical	Achiri et al., 2020.
		Extract of *Neorautanenia mitis, Derris elliptica, Metarhizium anisopliae, Beauveria bassiana*	Biological	January et al., 2020.
Leaf folder	Leaf folder *Cnaphalocrocis medinalis*	Fipronil, propenphos, chlopyriphos, monocrotophos, carbofuran, carbosulfan, imidacloprid	Chemical	Hurali et al., 2020.
		Azadirachtin, salannin, deacetylgedunin, gedunin, 17-hydroxyazadiradione, deacetylnimbin	Botanicals	Nathan et al., 2005.
		Pseudomonas stain (Pf1+ TDK1 + PY15), Cnme GV, (isolated from *Yangzhou*)	Biological	Jian et al., 2019.
Planthoppers	Brown planthopper *Nilaparvata lugens*	Endrin, carbofuran, disulfoton, chlorfenvinphos, phorate, methyl-demeton, dicrotophos, monocrotophos, imidacloprid, flonicamid, etc.	Chemical	Matharu and Tanwar, 2020.
		Extract of *Adhatoda vasica, Vitex negundo, Azadiracta indica, Ricinus comucies* and *Pongamia glabra* leaves, neem seed kernal extract, etc.	Botanicals	Longkumer and Misra, 2020.
		Conidial suspension of *Metarhizium anisopliae*, *M. flavoviride*, *Beauveria bassiana*, and *Hirsutelacitriformis*	Biological	Sharma and Sharma, 2021
	White backed planthopper *Sogatella furcifera*	Imidacloprid, buprofezin, thiamethoxam, chlorpyrifos, isoprocarb, cycloxaprid, buprofezin	Chemical	Luo et al., 2023.
		Leaf crude extract of neem, notchi (*Vitex negundo*), palmarosa (*Cymbopogan maurtini*) oil, jatropha (*Jatropha carcus*) oil, neem oil, etc.	Botanicals	Raj et al., 2020.
		Jinggangmycin (JGM) [product of *Streptomyces* var. *jinggangensis*]	Biological	Ge et al., 2017.

(contd.)

(Table 3 contd.)

Leafhopper	Green leafhopper *Nephotettix virescens* and *Nephotettix nigropictus*	Pymetrozine, imidacloprid, dinotefuran, sulfoxaflor, flonicamid, buprofezin, propaphos, disulfoton	Chemical	Adhikari et al., 2019.
		Karanj oil, mahua oil, pinnai oil, neem oil, custard-apple oil, seed oil and leaf and fruit extract of *Annona squamosa*	Botanicals	Kumar et al., 2021.
		Conidia and blastospores of *Beauveria bassiana*	Biological	Sharma and Sharma, 2021.
Rice hispa	Rice hispa *Dicladispa armigera*	Quinalphos, malathion, dimethoate, phosphamidon, endosulfan, chlorpyriphos, monocrotophos, cypermethrin, fenvalarate	Chemical	Bhattacharjee and Ray, 2017.
		Neem oil, Azacel, Calpaste, Larvocel, dk-bioneem, Multineem	Botanicals	Kumar et al., 2021.
		Powder formulation of *Beauveria bassiana* (Bals.) Vuill, spore extraction of *B. bassiana*	Biological	Purnima et al., 2013.
Rice bug	Earhead bug *Leptocorisa acuta*, gundhi bug *Leptocorisa oratorius,* rice mealy bug *Brevennia rehi*	Imidacloprid, triazophos, monocrotophos, thiamethoxam, acephate, carbaryl, malathion, lindane, etc.	Chemical	Gupta et al., 2019.
		Extract of *Chromolaena odorata, Azadirachta indica, Ricinus communis,* neem seed kernel powder (NSKP), etc.	Botanicals	Raveau et al., 2020.
		Isolates of entomopathogens (*Beauveria bassiana* and *Metarhizium anisopliae*), cow urine	Biological	Kumar and Sarada, 2020.
Gall midge	Rice gall midge *Orseolia oryzae*	Acephate, rynaxypyr, dinotefuran, fipronil, thiamethoxam, buprofezin, spinetoram, methoxyfenozide, acephate, dinotefurain, triazophos,	Chemical	Kumari et al., 2020.
		Neem Seed Kernel Extract (NSKE)	Botanicals	Ogah and Nwilene, 2017.
		Parasitized galls of *Platygaster diplosisae*	Biological	Minab et al., 2023.

of leaves of rice plants during highest tillering stage, removal of stubbles through plough and then burn at ground, drain out water in infested paddy field, seedling root dipping, removal of alternate grassy and other weeds hosts from seedbed, crop field and adjacent area shown very effective against leaf folder, stem borer, gall midge, rice hispa and rice bug (Bhatt et al., 2018; Kunal et al., 2020). Cultivation of certain suseptable aromatic rice cultivares like Pusa Basmati-1, Gobindabhog near main crop can be used as trap crop to reduce damage to the main crop (Katti et al., 2023). Crop rotation with leguminous pulse seed, potato, oil seed in low land and cultivation of maize in upland area are also shown good efficacy against different insect pests (Breidenbach et al., 2017; Chen et al., 2018). Uses of oil or electric light traps are very helpful against stem borer and planthopper (Bhatt et al., 2018). Even, use of fish like, *Puntius conchonius* (F. Hamilton, 1822), *Clarias batrachus* (Linnaeus, 1758), *Punctius ticto* (F. Hamilton, 1822), frogs like, *Euphlyctis cyanophlyctis*, *Duttaphrynus melanostictus* (Schneider, 1799) etc. and *Anas poecilorhyncha* (Forster, 1781) are preyed on adult of rice pest thereby reduce the population (Khatiwada et al., 2016; Yuan et al., 2022).

C. Biopesticides

Plant formulations, so called 'green pesticide' were also effective and have minimal residual activity (Raveau et al., 2020). Natural oil, cake and crude extract of different part of neem plant [*Azadirachta indica* (Juss, 1830)] neem oil, neem oil soap solution, neem seed oil, cake extract, leaf extract, leaf crude extract, seed kernel extract, limonoid, salannin, deacetylgedunin, gedunin, 17-hydroxyazadiradione, deaceytlnimbin, azadirachtin, neemgold, nimbicidine, neemax, azacel, and larvocelhave shown good efficacy against deleterious pest incidence (January et al., 2020; Shyamrao and Raghuraman, 2019; Dougoud et al., 2019). Application of extract of different part from other plants like seeds of *Pongamia pinnata, Madhuca longifolia, Calophyllum inophyllum, Neorautanenia mitis, Derris elliptica, Nicotinatobacum, Pongamia glabra*, *Chromolaena odorata, Ricinus communis*, *Adhatoda vasica, Andrograpis paniculata*, *Prosopis juliflora*, *Polygonum hydropiper, Lantana camara*, *Vitex negundo*, mixture of *Polygonum hydropiper,L. camara* and ginger-garlic-chili effectively reduced incidence caused by herbivores insect pests (Raj et al., 2020; Longkumer and Misra, 2020). Oil formulation from Mahogany, Palmarosa, Jatropha, custard-apple seed, Karanj (*Pongamia pinnata*), Eucalyptus (*Eucalyptus obliqua*), Cedar Wood, Mahua (*Madhuca longifolia*), Pinnai (*Calophyllum inophyllum*), Citronella, Vetiver, Catnip, were effective against *Dicladispa armigera* (Olivier), *Sogatella furcifera* (Horvath), *Nephotettix virescens* (Distant), *Nephotettix nigropictus* (Stal), *Scirphophaga incertulas* (Walker) population (Raj et al., 2020; Kumar et al., 2021; Raveau et al., 2020). Animal derived cow urine also acts as antifeedant and disinfectant against rice pests and their transmitting pathogens (Kumar and Sarada, 2020).

D. Biological control

Most popular biological controlling agents include mycobial powder and pesticide extracted from *Bacillus thuringiensis, Trichogramma japonicum, T. chilonis, T. dendrolimi, T. ostriniae, Lecanicillium lecanii, Beauveria bassiana, Metarhizium anisopliae*, *Skermanella* sp., *Pseudomonas* stain, CnmeGV galls of *Platygaster diplosisa* and Jinggangmycin (JGM) had shown good antibiosis effects through egg parasitic, larvicidal activity on rice insect pests (Dutta and Roy , 2022; Hajjar et al., 2023; January et al., 2020; Kumar and Sarada, 2020; Minab et al., 2023; Jian et al., 2019; Ge et al., 2017). Using of conidial suspension of *Metarhizium anisopliae*, *M. flavoviride*, *Beauveria bassiana*, and *Hirsutella citriformis*, preparations of marcescent mycelium of *Paecilomyces lilacinus*, wetable powder formulation, spore extract, conidia and blastospores extract of *Beauveria bassiana* had shown egg parasitoid activity on *C. polychrysus* (Meyrick), *D. armigera* (Olivier), plant and leafhopper (Purnima et al., 2013; Sharma and Sharma, 2021). Bio-pesticides Btprotoxin Cry1ca, NBAII- Bb-1, 4, 6, 8, 11, 15, 39 and 59 isolates, NBAII-Ma-1, 6, 10, 13, 15, 23, 25, 26, 41 and 42 isolates effective against *D. armigera* (Olivier) population (Baladhiya et al., 2018).

E. Resistant variety based control

Rice variety D518, IR-42, ASD7, and IR46 were effective against incidence by *N. lugens* (Stal.) and *S. furcifera* (Horvath) (Gao et al., 2020). Infestation potential of *C. medinalis* (Guenee) has recorded low in cultivar Ptb-12, TKM-6, Prasanna, Radha-4, Ramdhan, IRRI-6, KSK-282, DR-83, Bas-385 (Adhikari et al., 2022; Chen et al., 2022; Chatterjee et al., 2021). Similarly,GAR-13, IR-22, Gontra Bidhan 3, MTU-2020, IR-50, TKM 6, KMD1, KMD2, MTU15, and IR50 have shown good efficay against *S. incertulas* (Walker), *C.suppressalis* (Meyrick) and *C. polychrysus* (Meyrick) (Jha et al., 2023; Chavan and Patel, 2018a, 2018b; Xu et al., 2022). Pankhari 203, WRC25,

WRC34, WRC37, WRC40, WRC6, WRC7, WRC48, and WRC55 has recorded effective against *N. virescens* (Distant) and *N. nigropictus* (Stal) (Thein et al., 2019). Rice variety like IET-6286, Surekha, Usha, Sahbhagi Dhan, Sudha, Abhisek, ARC-5833, ARC-5984, TKM-6, and PTB-10 were effective against *O. oryzae* (Wood-Mason) and *S. inference* (Walker) incidence (Sanchit and Sanchit, 2019). Rice cultivar like Garem and Bengaubisi found effective against *D. armigera* (Olivier) infestation (Dutta and Hazarika, 1994). GR-9, Jaya, Dandi, Pawana, Gurjari, Narmada, Pawana, and GR-104 have shown good efficacy against *B. rehi* (Lindinger), *L. acuta* (Thunberg) and *L. oratorius* (Fabricius) (Khalifa and El-Rewainy, 2012; Morya and Kumar, 2019; Rath et al., 2020b).

F. Phoromone and allomone based control

Now a days farmers often use attractant sex pheromones (Z)-11-hexadecinal, (Z)-9-hexadecenal, (Z)-9-hexadecenal and (Z)-11-hexadecenal with PVC matrix, Z11-16 Acetate, (Z)-hexadec-9-enal, (Z)-11-octadecenal, (Z)-11-hexadecenyl acetate, (Z)-13-octadecenyl acetate, pymetrozine, 2-(E)-octenyl acetate, octanol, n-tridecane and 2S,6S-diaxetoxyheptane which help in attract male and female mass trapping and mating disruption of insects for management of rice pest (Gunawardena and Ranatunga, 1989; Dutta and Roy , 2022; Liu et al., 2020; Dang et al., 2016; Song et al., 2022). Some repellent allomone 5: 1 mixture of 2-(E)-octenyl acetate and octanol 3-octenal, 1-octanol, (Z)-3-octenyl acetate, extracts of Bamboo (*Bambusa levis* L.), Ginger (*Catimbium haenkei* L.), Malubago (*Hibiscus tiliaceus* L.) repel herbivore stem borer, leaf folder and gandhi bug population (Gunawardena and Bandumathie, 1993).

G. Population based control

Several demographical models described the biotic and abiotic mortality factors affecting its abundance, development, survivorship, reproduction, in agroecosystem (Mobarak et al., 2020). Developing of age-specific (horizontal) and stage-specific (vertical) life tables for assessing population density, fluctuation, most vulnerable stage or stage having higher mortality rate of different rice pests under different agroclimatic field conditions (Dutta and Roy, 2016; Dutta et al., 2020, 2021). Population growth and reproductive parameters [probability of survival from birth to age x (l_x), survival rate (s_x), average population alive in each stage (L_x), total individuals at age x and beyond k (T_x), life expectancy (e_x), generation survival (GS), age specific fertility or fecundity (m_x), gross reproductive rate (GRR), net reproductive rate (NRR or R_0), intrinsic rate of population increase (r_m), finite rate of population increase (λ), weekly multiplication rate (λ^7), increase rate per generation (λ^{Tc}), total fertility rate (F_x), population growth rate (PGR), and population momentum factor of increase (PMF)], mortality profiles [proportion dying each age (d_x), mortality rate (q_x), and mortality coefficient (MC)], span of generation time (T_c) and doubling time (DT) dpend on temperature, nutritional quality [quantity of carbohydrates, protein, lipid, phenol, phytate, saponein etc.] host system [rice host (*O sativa*), non rice host (eg. *E. colona, C. rotundus,* etc.)], presence of egg and adult predator parasitoid (Babamir-Satehi et al., 2022; Schoonhoven et al., 2005; Dutta and Roy, 2018a, 2018b; Harborne, 1973, 1984; Manikandan et al., 2015; Havelka and Zemek, 1999). By analyzing life table data of rice peests in different host and agro-climatic condition type -II survivorship has shown by *S. furcifera* (Horvath) but type-III survivorship obtained in *S. incertulas* (Walker), *N. lugens* (Stal), *L. acuta* (Thunberg) and even, type IV exhibited by *C. suppressalis* (Meyrick) and *C. polychrysus* (Meyrick) (Dutta and Roy, 2016, 2018b; Shivasharanappa et al., 2010). By studying population dynamics, sixth nymphal stage of *L. acuta* (Thunberg), first instar larva of *S. incertulas* (Walker), *C. suppressalis* (Meyrick), *D. armigera* (Olivier), fourth nymphal stage of *N. lugens* (Stal) and first nymphal stage and adult of green leafhopper have identified most vulnerable stages (Win et al., 2009, 2011). Ecological limiting factors like relative humidity in winter, low moisture, predator density and dispersal loss during larval stage, egg predator [eg. *Conocephalus chinen*sis (Redtenbacher)], high temperature, low relative humidity, parasitisation by the entomopathogenic nematode, adult migration, parasitoids of of egg, nymphal and adult, moulting failure of larva into pupa and host nutritional quality appeared as limiting factors *N. virescens* (Distant), *N. nigropictus* (Stal), *S. furcifera* (Horvath), *D. armigera* (Olivier), *C. suppressalis* (Meyrick), *L. acuta* (Thunberg) and *O. oryzae* (Wood-Mason) (Kumar et al., 2012; Dutta and Roy, 2016; Win et al., 2011; Suzuki et al., 1996; Roy, 2022). Parasitoids and disease on 3rd and 4th instar larva and pupal parasitism also appeared as limiting factor for *C. medinalis* (Guenee) (Huang et al., 2020; Padmavathi et al., 2008). 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, 2019a, 2019b, 2020, 2021).

CONCLUSIONS

Rice, one of the most consumable sataple crop of most of Bengal household cultivzted 56.63 lakh hectare areas with a production of 274.37 lakh tones, contributing about 20.69% to the total net State Domestic Product (SDP) (Dutta and Roy, 2022; Jha et al., 2023; Adak et al., 2020; Chakraborty and Deb, 2012). Rice in West Bengal has cultivated in the six agro-climatic zone during three different cropping seasons, Aus (autumn rice), Aman (winter rice) and Boro (summer rice) (Adhikari et al., 2012; Chakraborty and Deb, 2012). But this rice production in West Bengal was hampered by different biotic stresses causing 33% production loss (Aryal et al., 2018; Jha et al., 2023). Most important biotic stress caused to hamper production of rice in West Bengal was through direct or indirect infestation by phytophagous rice pest (Adhikari et al., 2012; Dutta and Roy, 2022). The remarkable deleterious rice insect pest fauna has observed mostly are *S. incertulas* (Walker), *S. inference* (Walker), *C. polychrysus* (Meyrick), *C. suppressalis* (Meyrick), *C. medinalis* (Guenee), *N. lugen*s (Stal.), *S. furcifera* (Horvath), *N.virescens* (Distant), *N.nigropictus* (Stal), *D. armigera* (Olivier), *L.acuta* (Thunberg), *L. oratorius* (Fabricius), *O. oryzae* (Wood-Mason) etc. (Azgar and Hembram, 2018; Dhaliwal et al., 2010; Jha et al., 2023).

It has observed that most of polyphagous major rice pests in rice mainly beside that they were also aggregated on some alternative non rice weeds found in and around rice field (Bhatt et al., 2018; Dutta and Roy, 2018a, 2018b). Population growth, reproductive and mortality parameters of different rice pests are greatly varied depending on host system and agroclimatic conditions (Roy, 2017, 2022; Reji and Chander, 2008). Modern agriculture concerned with ecofriendly and sustainable climate smart agriculture (CSA) as a part of ecological pest management (EPM) based integrated pest management (IPM) for of different economic crops (Pedigo et al., 1986; Pedigo and Higley, 1992; Aryal et al., 2018; Chávez et al., 2018; Roy, 2019b). Therefore, basic information reguaring pest ecology is necessary before deciding any strategy to combat with deleterious rice pest (Rahaman et al., 2014; Roy, 2019b). Commonly most of farmers use different synthetic pesticides for controlling pests (Aktar et al., 2009; Bais et al., 2017). But some plant extract botanicals are also seen against rice pests (Aryal et al., 2018; Shitiri et al., 2014; Dutta and Roy, 2022). Beside these most popular controlling methods usually mechanical and cultural control strategies include mechanical synchronised 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, remove, burn or plough the stubbles, and using of fish, frog ducklings etc. also seem to be useful for controlling these pest population (Ayelo et al., 2021; Khatiwada et al., 2016; Bhatt et al., 2018). Some attractant sex pheromones like, (Z)-11 hexadecinal, (Z)-9-hexadecenal, (Z)-ll-hexadecenal, (Z)-9-octadecenal are show good efficacy in mass trapping and mating disruption of deleterious insect pests (Liu et al.,2020; Dang et al., 2016; Gunawardena and Ranatunga, 1989). Beside that repallent allomones like, 5: 1 mixture of 2-(E)-octenyl acetate and octanol 3-octenal, 1-octanol and extracts of resistant rice varieties distracts rice pests' population from cultivated field (Gunawardena and Bandumathie, 1993; Pathak and Khan, 1994). Farmers some time use biological agents as pesticides derived from strains of *Bacillus thuringiensis*, *Beauveria bassiana, Metarhizium anisopliae*, *M. flavoviride* etc. which were effective against major paddy pests (Dutta and Roy, 2022; Purnima et al., 2013; Sharma and Sharma, 2021). Certain resistant rice cultivers like, Pankaj, Triveni, IR-19362-183, IR-20, H4, IR-36, IR-50, IR-9828-23-1, IR-13429-57-1, IR-44, IR-22, and GR-9 etc. have impart resistance effect against rice pest population growth, development and reproductive parameters (Sanchit and Sanchit, 2019; Huang et al., 2019; Rath et al., 2020b).

Recent days, farmars generally use synthetic chemical insecticides indiscriminately against those pests for the hope of high production of rice, but it has seen that these pesticide not only target phytophagous rice pests but also targeted beneficial natural enemies of pest, pollinator resulting destabilizing of biodiversity, decrease the sustainability by bio-magnification and bio-accumulation of toxic substance which result in ecologically and environmentally imbalance and creates health hazars (Katti et al., 2023; Biswas et al., 2006; Aktar et al., 2009; Kumari et al., 2020). It has seen that excessive use use of insect lethal insecticides leads to increase the amount of primary nutrient like amino acids and sucrose available in the phloem of rice plants results in insecticide-induced resurgence, and cross resistance leads to of periodic outbreaks pest populations, known as "Moran effect" (Bottrell and Schoenly, 2012; Dutta and Roy, 2016, 2022). To overcome this constrains caused by rice pest researchers usually use insecticide by considering several parameters like cost: benefit ratio, economic threshold level (Selvaraj et al., 2012), population dynamics by exploring of allelopathy-based strategies and enhancing use of green pesticides and cultural methods for appropriate management strategies for rice pests (Dutta and Roy, 2022). Thus, population ecology based sustainable management of such pest species will support E^3 strategy [Ecosystem service-based Ecological engineering for Ecological pest management (ESS-EE-EPM)] of pest management for successful cultivation of rice in the near future.

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