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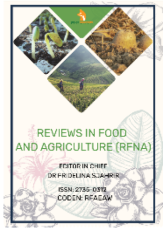

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REVIEW ARTICLE

MANAGEMENT TRENDS OF RICE INSECT PESTS IN SOUTH ASIA: A REVIEW

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ABSTRACT

Rice is a staple food to over half of the world population. It is an economically important crop throughout South Asia. Rice in this region is susceptible to insect pests such as Planthoppers, Leafhoppers, Stem borers, Hispa and many others. Several management practices have been adopted in the region since historic times. The management practices include cultural, biological and chemical methods in addition to integrated and miscellaneous approaches. Rice farmers in the region rely heavily on the conventional cultural practices. However, the trend is shifting slowly to the chemical approaches with gradual increase in availability and affordability of synthetic insecticides. Integrated Pest Management (IPM), which focuses on sustainable crop production, has shown promising results. Modern management techniques such as genetic modification, use of digital technology, resistant cultivars, fungal entomopathogens etc. are more effective and eco-friendly. The focus at present should be the adoption of modified cultural methods, judicious application of chemicals, use of resistant cultivars and exploitation of biological resources.

KEYWORDS

Eradication, Insect Pest, Invasive, Management, Rice, South-Asia

1. INTRODUCTION

Rice is one of the most important food crops globally, second to wheat. It constitutes the staple food for about 50% of the world population which includes over 2 billion Asians(Zeigler & Barclay, 2008). It is primarily a subsistence crop since half of it is consumed at the places of its production(Litsinger, 2009). Rice is grown in at least 114 countries of the world comprising most of the developing nations of Asia and Africa.

Rice is considered an ideal host for many insect species since it's grown in warm and humid environments which aid their survival and proliferation(Dale, 1994). Insects, in general, are the diverse group of animals in the Phylum Arthropoda consisting of three-pairs of jointed limbs with the chitinous exoskeleton, compound eyes, one pair of antennae and three body parts (head, thorax and abdomen.). They have been evolving for around 350 million years and consist of over 6 million identified species at present. Out of these, nearly 3000 species have been listed as the pest, causing significant damage in agricultural crops(García-Lara & Saldivar, 2016).Insects are considered as pests if they are present in significant numbers and are at a competition with humans for resources. So, the term pest can be considered as an arbitrary label(Metcalf & Luckmann, 1994). Over 800 species of rice insect pest have been noted globally, of which 20 species are of major economic importance in tropical Asia. The number is about the same for Africa and the Americas(Way et al., 1991). Over 125 species of insect have been reported in the paddy fields of India of which only 15 to 20 insect species are reported to be hostile(Kalode, 2005). Rice insects infest all parts and growth stages from sowing till the harvest. In addition to the direct damage by feeding, some insects transmit disease pathogens such as the Tungro virus leading to low rice yields(Pathak, 1968). The insect-damaged parts also enable the entry of other fungal and bacterial pathogens.

The insects of rice are either monophagous, feeding only on rice plants or polyphagous, moving in and out of the field(C. N. Bambaradeniya & Amerasinghe, 2004).Ages of coexistence have led to the coevolution of insects and plants as a result of which several interactions like insect predation of plants and plant defences against herbivorous insects have arisen(Gatehouse, 2002). Before adopting the appropriate management practices, it is essential to distinguish between the harmful and beneficial insects(Zeigler & Barclay, 2008).

Recently there have been growing concerns of invasive insect species not just in agriculture but also in human health, forestry and biodiversity. In addition to their rapid growth, generalized diet and prolific breeding these insect species tend to be long-lived, voracious, aggressively pervasive and resilient. They also have the ability to cover long distances in short periods(Rejmánek & Richardson, 2000). Biological invasion of insects is the result of their emergence followed by rapid adaptation to a new environment(Way et al., 1991).

2. HISTORIC TRENDS

2.1 Insect Pest as Problem

Farmers have been selecting the best yielding rice cultivars for nearly 9000 years that includes insect-resistant varieties(Norton & Way, 1990).Rice is indigenous to Asia since its domestication some 6000 years ago(Ponting, 1991). With around 41% arable land, South Asia is the leading rice-producing areas in the world at present(Gumma et al., 2011).

The prevalence of insects pests in South Asia dates back to ancient times. Accompanied by the expansion of foreign trade, insect pests have been imported from various parts of the world in this region. *Eriosomalanigerum*, Woolly apple aphid was first reported in India in 1889

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from the imported rootstock of Chinese apple(Mishra, 1920).Similarly, Potato Tuber moth was imported to India from Italy in 1937 and spread to the surrounding countries(Singh, 2004). There have been several other instances of accidental insect pest introduction in South Asia.

The severity of destruction by the insect pests have changed over time. The ear-cutting caterpillar *(Mythimna separata)* in the 1960s was a major insect pest of Bangladesh but now has been less problematic. In addition, the incidence of leaf rollers *(Cnaphalocrocismedinalis, Marasmiaexigua)* has increased since the 1980s(Sarkar et al., 2013). This dynamics is not limited to the insect species alone but also to the range of the crops affected. Till 2009, *Phenacoccussolenopsis* was recorded in 84 host plants under 28 families. It was formally recognized as a cotton pest but now is a threat to most cultivated crops(Sridhar et al., 2014).

In the pre-war periods in Japan, the endemic rice damage was attributed to the Borers *(Tryporyzaincertulas, Chilosuppressalis)* and Brown planthopper (*Nilaparvatalugens)*(Kiritani, 1979). **S**everal other outbreaks of rice insect pests have been reported in Asia in past decades. Rice planthoppers caused significant damage to East Asian countries like Vietnam, China and Japan in 2005. Imidacloprid and Fipronil (insecticides) resistance were noted in Brown planthopper and White-backed planthopper respectively.(Matsumura & Sanada-Morimura, 2010).During September 2008, an outbreak of Brown planthopperwas seen in basmati rice in Haryana and Western Uttar Pradesh, because of the favourable weather conditions(Bambawale et al., 2009).A more recent incidence of rice damage was observed in India during July-August 2018 triggered by the Fall Armyworm *(Spodoptera frugiperda)* along with the associated natural enemies(Shylesha et al., 2018).These devastating outbreaks prompt the need for appropriate insect pest management for the future.

2.2 Historic Management approaches

The major issue for the subsistence rice farmers in Asia is the control of insect pests(Kiritani, 1979).In tropical Asia, small-scale farmers have effectively controlled pest damage for centuries using a diverse set of conventional methods and local resources(Brown & Marten, 1986). Manipulation of the natural enemies was perhaps the major management strategy to control the pests in conventional farming(Glass & Thurston, 1978). Historically, AWPM (Areawide Pest Management) had been practised since the late 1800s which focused mainly on orchestrated and coordinated assault techniques rather than the field-by-field strategy.(Faust et al., 2008) It can be compared with the modern-day IPM (Integrated Pest Management).

Iskandar (1980) reported the use of insectivorous wild birds like brown-throated sunbird (*Anthreptesmalacensis*) and little spider hunter sunbird (*Arachnotheralongirostra*) for the management of insect pests like caterpillars in some parts of Indonesia. Similarly, ducks have been used in the Javan rice fields to control the insect population(Iskandar, 1980). Chinese citrus growers used the nest of predator ants, *Oecophyllasmaragdina,* to minimize the population of foliage-feeding insects in mandarin orange trees. This practice dates back to 900 AD and is considered one of the oldest methods of biological control of insect pests by protecting natural enemies(L. Ehler, 1998). In Japan, Rice borers were controlled mostly by the cultural methods, historically, that included changing transplanting dates, flooding fallow fields, hand removal of egg masses, digging or burning of stubbles, use of light traps and so on. In addition, dropping whale oil in irrigated water was practised to combat Brown Planthopper, before the advent of synthetic insecticides(Kiritani, 1979). Synthetic chemical pesticides have been an effective management technique practised globally in recent years. However, unfair use of pesticides has distorted the natural control mechanisms giving rise to "secondary pests" by destroying their natural enemies. Farmers are forced to use the pesticides further to control the new pests(Kiritani, 1979).

In South Asian regions, insect pest management was done on two bases. The first one was targeting insect pests directly by mechanical, cultural and biological methods i.e. use of rice insect pathogens and use of predators alongside non-chemical methods. The second one was the indirect (ecological) method comprising mixed and trap cropping. Synthetic chemicals were not much in use(Brown & Marten, 1986).

3. Current Scenario

The South-Asian region, also known as the Indian subcontinent, holds over 20% of the world population and almost the same percentage of undernourished people. Here, rice is a staple to nearly 1.7 billion people and a primary means of livelihood for over 50 million households. Only India and Pakistan are self-sufficient in rice so far(Bishwajit et al., 2013). In addition to economic importance, rice has immense religious and cultural significance throughout the region(Aryal & Kandel, 2017) Rice is grown in warm and humid environments of South Asia, favouring the survival and proliferation of insects. The key insect pests of rice in the region include stem borer, leaf folders, brown planthoppers and green leafhoppers(Gianessi, 2014b). In addition, brown planthopper, rice bug, caseworm, leaf miner, rice hispa, stem borers (yellow, dark-headed and pink) have been historically significant and are still the major insect pests of South Asia(Ane & Hussain, 2016; Fujisaka et al., 1994).Even if the global losses due to insect pests have declined from 13.6% to 10.8% post-green revolution, the losses at present are still economically significant.(G. S. Dhaliwal & Koul, 2010). Yield loss in rice ranges between 21 to 51% because of insects like stem borer, gall midge and planthoppers (Pasalu et al., 2004).Stem borer alone causes 2.3% yield loss in rice (Savary et al., 2000). Planthoppers and leafhoppers are not just important to South Asia but also to the other major rice producers of the world. Various strategies have been formulated to keep their population at a normal level.

Yellow stem borer and Brown planthopper have been the major insect pests of rice in South Asia in addition to Green leafhopper, Rice hispa, Leaf folder and Gall midges(Geddes & Iles, 1991).

In rice-growing Asian countries, lack of knowledge of insect pests among farmers is a serious issue. Most farmers do not consider pest management while making farm decisions(Heong & Sogawa, 1994). At present, South Asian rice farmers are using insecticides extensively for controlling the insect pests. The degree of usage however varies in different countries. In Bangladesh and India, insecticides are used in nearly 50% of rice fields. It was reported that the sales of insecticides increased from US$409 million in 2009 to US$674 million in 2012 in South Asia alongside SouthEast Asia. This has led to increased use of new selective insecticides in the region, especially India(Gianessi, 2014b).

Several factors are associated with the spread of insect pests over time, of which. globalization, international trade and climate change are considered to be the major ones. Burgiel et. al (2006) have mentioned trade, transport, travel and tourism as the key routes for the introduction of invasive alien species. The route includes means (e.g. aircraft, train), intent (e.g. agriculture, forestry) or goods (e.g. timber)(Burgiel et al., 2006). Globalization has increased agricultural trade and the movement of seeds as well as planting materials from one part of the world to the other. This has contributed to the introduction and proliferation of invasive insect pests in new environments leading to heavy crop damage and even extinction of some indigenous insect species(Moore, 2005).

Climate change has accelerated the global temperature rise. New reports have predicted a 2 to 5° C rise in global surface temperature by the end of this century. This may cause some severe impacts on agricultural production since the latest findings have indicated greater insect damage to crops in warmer climates(Riegler, 2018).

International trade is considered to be the major force determining the distribution of invasive insect species globally(Evans et al., 2018). Introduction of invasive exotic species to new locations are mostly accidental leading to unprecedented consequences(Costello &McAusland, 2005). So, the focus must be directed towards prevention by following proper quarantine measures. Outbreaks of insect pests in Indian sub-continent are mainly associated with the cultivation of modern varieties lacking insect resistance. In addition to it, year-round cultivation of rice, use of high levels of nitrogen fertilizers and extensive use of insecticides have increased the frequency of outbreaks. (Chelliah et al., 1989).

4. Invasive Insect Pests and Their Control

4.1 Stages of invasion

Invasion by an insect occurs in a series of steps viz. introduction, spread and naturalization(Rejmánek & Richardson, 2000). Biotic invasion can cause extinctions of vulnerable native species through predation, competition, and habitat alteration(Geburzi& McCarthy, 2018). Natural enemies of insects are absent in new environments. So their introduction to such environments may cause rapid insect pest outbreaks and invasions. One of the most invasive insect pests in Asia is the rice water weevil *(Lissorhoptrusoryzophilus)*, which is native to North America(Chen et al., 2005).

The common features of effective management programs against biotic invasions include the selection of right strategy, consistent use of appropriate resources and continuous support of public and funding agencies(Mack et al., 2000).

Table 1: List of important Insect pests of Rice in South Asia

S. N	Scientific Name	Common Name	Stage of Infection	Characteristic damage	Stage of rice affected	Economic threshold	Prevalence (major)
1	*Nilaparvata lugens*	Brown planthopper	Nymph	Plants wilt and dry (Hopper burn)	All (from seedling to maturity)	10 insects per hill at veg. 20 insects/hill at a later stage	India, Srilanka, Bangladesh, Pakistan
2	*Scirpophaga incertulas*	Yellow stem borer	Larva	Death of central shoot (Dead heart) white ear, Loss of tillers	All (from seedling to maturity)	10% DH or 1 egg mass 1 month/m2	India, Nepal, Srilanka, Bangladesh, Pakistan
3	*Orseolia oryzae*	Gall midge	Maggot	Central leaf sheath modified to Silver shoot, Loss of tillers	Growing bud	5% (at the active tillering stage)	India, Srilanka, Bangladesh
4	*Leptocorisa sp.*	Rice/Gundhi bug	Nymphs, adults	Partial chaffy grains, panicles discolouration with empty or ill filled grains	milk stage of grains.	1 nymph/adult per hill	India, Nepal, Srilanka, Bangladesh
5	*Cnaphalocroci medinalis*	Leaf folder	Larvae	Leaf damage, ill filled grain	All (from seedling to maturity)	3 damaged leaves/hill post active tillering stage	India, Srilanka, Bangladesh, Pakistan
6	*Chilo spp.*	Stemborer	Larva	Death of central shoot (Dead heart) white ear, Loss of tillers	All (from seedling to maturity)	10% DH or 1 egg mass 1 month/m2	Nepal, Bangladesh
7	*Sogatella furcifera*	White-backed planthopper	Larva	stunting, fewer tillers, loss grain weight, (hopper burn)	more abundant during the early stage and tillering phase	10 insects per hill at veg. 20 insects/hill at a later stage	India, Bangladesh, Pakistan
8	*Ripersia oryzae*	Mealybug	Adult, Nymph	Stunting, yellowish curled leaves, spots	All stages	1 nymph/adult per hill	Bangladesh, Pakistan
9	*Nephotettix spp.*	Green leafhopper	Nymph, adult	Vector of tungro disease, Plants wilt and die in severe cases	Seedling, Vegetative and growing stages	2 insect/ hill in tungro endemic areas. 20-30 insects/hill in other areas	India, Pakistan
10	*Dicladispa armigera*	Rice hispa	Both the adult and larvae	Scrapes the upper surface of the leaf, Tunnels in the leaf tissues. Eggs inside the leaf tips	All (from seedling to maturity)	35% leaf damage,1-2 adults/hill	India, Bangladesh
11	*Mythimna separata*	Ear-cutting caterpillar	Larval	Defoliation and damage to rachillae	Panicle stage	1 leaf/ hill stray incidence prior to harvesting	Bangladesh
12	*Spodoptera mauritia*	Swarming caterpillar	Larval	Defoliation and damage to rachillae	Seedling, Early tillering stages	1 leaf/ hill stray incidence prior to harvesting	Bangladesh
13	*Thrips oryzae*	Thrips	Larva	Stunt plant growth, Papery and distorted leaves	Vegetative, Growing and Fruiting stages	20% damaged hills, 1-2 cases/hill	Bangladesh

Modified from: (Ane & Hussain, 2016; Geddes & Iles, 1991)

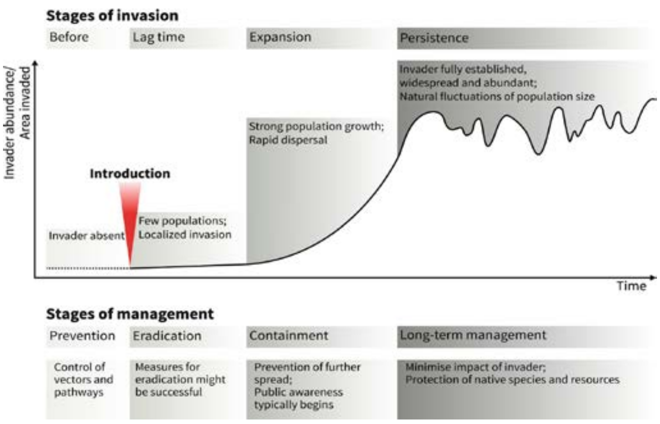

Figure 1: Theoretical curve depicting stages of management with respect to phases of invasion

Adopted from:(Geburzi& McCarthy, 2018)

4.2 Prevention

The best and the most successful technique that can be deployed against any insect pest is the prevention of invasion which is much less expensive than post-entry monitoring. The first step towards prevention is the identification of potentially invasive species and following the standard quarantine protocols(Mack et al., 2000). However, control and mitigation measures should be followed if the pest is introduced accidentally and begins to spread rapidly(Geburzi& McCarthy, 2018)

4.3 Eradication

Eradication usually refers to the elimination of every single individual of a species without any future prospect of recolonization. It is one of the extreme measures employed for insect pest management. Elimination of an exotic species is possible only if it is discovered at initial stages and resources are used early on(Simberloff, 1997). Eradication is advised to be carried out if the long-term cost of damage by a particular insect pest is greater than the short-term cost for its removal(Myers et al., 1998). This measure is also suitable for those pests displaying high risk of invasion. Two years or two generations of survey data are considered to ensure complete eradication for most of the insect species(Gupta et al., 2019). Eradication projects of some lepidopteran, coleopteran and dipteran insects involved mass trapping in combination with other approaches(Myers et al., 1998).

4.4 Management

Different management techniques are used for controlling insect pests e.g. Biological practices, Cultural practices, Chemical controls, Mechanical approaches and so on. There are no universal practices for the management of invasive insect pests. Adoption of the right management strategy depends on the type of organism, population size, biology, ecology, pest status, economic significance and available control options. Identification of natural enemies, production of resistant cultivars, judicious use of insecticides to avoid resistance and resurgence, modification of crop management practices, development of appropriate IPM programs and adequate Phyto-sanitation measures have been crucial in combating invasive insect pests in rice(Gupta et al., 2019)

5. Current Management Practices of Rice Insect Pests

5.1 Cultural methods

Cultural practices are common agronomic practices which are followed to increase the productivity of crops and are useful in the suppression of pests at the same time(Reddy et al., 1979). Crop rotation, intercropping, tillage, use of cover crops and mulches, management of irrigation, drainage, maintenance of correct spacing, seasonal planting etc. are important cultural practices adopted for insect pests management(Chandola et al., 2011; Faust, 2008).

Crop rotation breaks the life cycle of insect pests such as gall midges in rice fields(Heinrichs & Muniappan, 2017). Tillage, an important cultural practice, destroys the natural habitat of egg, larva and pupae of soil-borne insects. Chandola et al. (2011)observed the use of Barnyard millet (*Echinochloa sp.*) and Konri millet as trap crops of rice to reduce pest damage(Chandola et al., 2011). Some researches have shown the population of hopper and stem borer being affected by fertilizer management. Application of nitrogen at optimum dosage with 2-3 splits avoids the build-up of insects such as Gall midges, Leaf folder, Brown plant hopper and White Backed plant hopper in rice(Reddy et al., 1979). Similarly, transplantation of the older seedlings is reported to reduce the exposure of vegetative-stage-pests such as caseworm and whorl maggots. Other preferable cultural practices include shifting of planting time e.g. early planting which limits the population of gall midges and late planting which lowers the incidence of leaf folders. In addition, flooding rice stubble after harvests have shown a lower incidence of armyworms and stem borers in the succeeding seasons(Heinrichs & Muniappan, 2017). Use of undecomposed farmyard manure is discouraged since there is a greater occurrence of white grub and other pests. The larval and early stages of the insects feed on undecomposed manure and proliferate leading to severe crop damages. Some traditional practices to reduce insect pests in Indian subcontinent include the application of table salt and setting up fire in the fields. Application of table salt controls white grub, stem borer and even wilt disease to some extent while setting up fire ensures sterilization of the field from potential insect pests(Chandola et al., 2011).

5.2 Biological methods

The biological management of insect pests involves the use of natural enemies, hormones, antimetabolites, feeding deterrents, repellants, pheromones and so on. Besides these, genetically modified host resistance cultivars are developed to control the damage of insect pests(Faust, 2008). The use of biological control agents has been one of the promising alternatives to insecticides and other control methods since it's safe and sustainable(Kumar et al., 2008). Accounting for nearly 60% of natural pests control, Biological methods are the foundations of Integrated Pest Management. They balance the natural enemies by minimizing the use of synthetic chemicals efficiently(Pasalu et al., 2004; Rao, 1983).

Natural enemies are among the most preferred tools for biological control since insect predators are found in almost all agricultural and natural environments. Some of the macro-predators include beetles, bugs, bees, spiders, wasps, predatory mites and so on. Chinese ladybird *(Harmonia axyridis)*, is one of the insects used as a predator of aphids. Similarly, spiders feed on Brown plant hopper and white-backed planthopper(Pasalu et al., 2004). Some wasps and flies are considered parasitoids since they lay eggs and raise larvae on the bodies of other insects. The larva feeds on the host and kills it eventually(Wyckhuys et al., 2019). As a biological control strategy, either locally available natural enemies of pests can be preserved or new natural enemies can be imported(L. E. Ehler, 1998). The activity of natural enemies mainly governs the extent of damage by insects. In tropical Asia, the prevalence of abundant natural enemies has lessened the insect pest problems in rice(Heinrichs EA, 1994; Rao, 1983).

In addition to predators and parasitoids, some microscopic parasites are also used to control specific insect pests e.g.*Trichogramma* is a parasite of stemborer and leaf folder whereas *Platygaster* infects gall midges. Similarly, *Bracon spp.* infects the larva of rice Hispa(Pasalu et al., 2004). In many parts of the world, the history of rice cultivation has allowed stable relationships to develop between rice pests and their natural enemies. The species diversity and abundance of the predator populations can be greater than those of the pest populations when little or no pesticides are used(C. N. B. Bambaradeniya & Amarasinghe, 2003).

A number of rice cultivars, resistant to certain insect pests, have been released in South Asia. Among these, Ratna, Sasysree and Vikas are resistant to Stem borers. Varieties such as Sneha, Pothana, Kavya, Ruchi, Samridhi can tolerate Gall midge. Chaitanya, Krishanaveni, Vajram, Pratibha etc. are effective against Brown planthopper. HKR 120 is resistant against white-backed planthoppers. Similarly, Vikramaraya, Lalat, Khaira and Nidhi are resistant against Green leafhoppers(Pasalu et al., 2004).

There are certain groups of chemicals called semiochemicals that are released by some plants and animals. They have the potential to trigger some behavioural and physical responses in other organisms. These chemicals may have both intra- and inter-specific effects. Such semiochemicals and pheromones are used to attract and trap different species of insect pests. After identification and tracking one of the three approaches can be followed viz. mating disturbance, 'lure and kill' and mass trapping(Regnault-Roger, 2012). The diffusion of artificial pheromones in high concentration prevents pheromone-tracing between opposite sexes leading to mating disruption in insects(El-Sayed et al., 2006).The pheromones used, mostly are the male attractants. The efficacy of management could greatly be enhanced by the use of Kairomones, which are both male and females attractants. These are the odors of the host or prey of insects. If female attractants could be used, virgin and mated females can be eliminated resulting in reduced insect population. Sex pheromones are effective alernative to light traps for monitoring insects such as yellow stem borer and leaf folder(Katti, 1999). Such pheromones of Gall midge and Rice hispa have also been detected(Krishnaiah, 1995). Mass trapping by installing 20 sleeve traps per hectare with 5 mg pheromone could reduce the Stem borer damage by about 70%. Integration of two non-insecticidal components, viz. Pheromone Mediated mass trapping and biocontrol through *Trichogrammachilonis*(parasite), are suggested for controlling yellow stem borer and leaf folder(Katti, 1999).

Lure and kill technique is successful against Dipteran and Coleopteran insects, in addition to the few lepidopterans. It utilizes less pheromones, making it cost-effective. But the semiochemicals used in this technique can attract natural enemies of insect pests and other non-targeted insects. This drawback should be considered before adopting 'lure and kill'(El-Sayed et al., 2009).

The amount of semiochemicals used for mass trapping is relatively small and their toxicity is highly selective to the target species. Mass trappings are found to be more successful in multivoltine, polyphagous, and polygamous species than in univoltine, monophagous, and monogamous species of insects(El-Sayed et al., 2006).

In addition to the above mentioned biological methods, some botanical pesticides are also in use. Neem formulations are considered an effective alternative to synthetic insecticides. These are potent against Brown Plant hopper, White backed plant hopper, green leaf hoppers and leaf folder to some extent. Neem formulations do not kill the insect pest directly but deprive them of reproduction, feeding and other biological activities(Pasalu et al., 2004).

In order to escape repetitive invasion, the primary intention of biological control is to reduce the establishment and persistence of pests and increase their enemies. This is one of the few fields of study where the concept of Allee effect has been well understood and exploited successfully. The Allee effect highlights the significance of critical density, at which the given aggregation unit (population, colony or social group) is likely to become extinct. The first breakthrough in its application came with biological pest control in which the population of insect pests was overpowered with sterile males(Courchamp et al., 1999). An eradication program against screwworm fly (*Cochliomyia hominivorax*) in the United States also involved the use of sterile males(Dahlsten, 1986).

5.3 Chemical methods

The chemical method includes a broad range of synthetic organic, inorganic and natural chemicals like pyrethroids, insect growth regulators and fumigants(Faust, 2008). Chemical control has been a common strategy for pest management in South Asia. In the 1970s and 1980s, subsidies provided by the Asian governments for the insecticides increased their usage rapidly. Insecticides were included in the loan packages along with the fertilizers(Gianessi, 2014a).

The common insecticides used in South Asia include organochlorine endosulfan; organophosphates like methyl parathion, monocrotophos and chlorpyrifos; carbamates such as carbaryl and carbofuran; pyrethroids such as cypermethrin and deltamethrin. Two to three insecticide applications are made by Asian rice farmers commonly. The application could be as high as six to seven at times. This doesn't apply to the majority of farmers since they use preventive measures over control measures(Pingali&Gerpacio, 1997).

Table 2: Spectrum of effectiveness of Major insecticides used against Rice insect pests in Indian subcontinent

Insecticides	Dose g a.i/ha	Application type/form	Stem Borer	Leaf folder	Hipsa	Brown Plant Hopper	White Backed Planthopper	Cut worms	Green Leaf Hopper
Monocrotophos	400	Spray	***	***	**	***	***	**	***
Fipronil	50		***	***	**	***	***	**	***
Chlorpyrifos	500		***	***	**	-	**	**	-
Phosphamidon	500		**	***	**	***	***	-	**
Carbaryl	750		*	**	**	***	***	-	**
Phosalone	500		***	**	***	**	-	-	**
Quinalphos	500		**	***	**	-	**	-	-
Insecticide	**Dose g a.i/ha**	**Application type/form**	**Stem Borer**	**Gall midge**	**Whorl Maggot**	**Leaf folder**	**Hipsa**	**Brown Plant Hopper**	**Green Leaf Hopper**
Isazophos	600	Granular	***	***	**	***	-	***	***
Fipronil	75		***	***	**	**	**	***	**
Carbofuran	750		***	**	***	-	**	***	**
Fenthion	1000		***	**	**	***	-	-	-

Note: * Moderately effective ** Effective *** Highly effective

Modified from: (Pasalu et al., 2004)

It is a well-established fact that judicious application of insecticides ensures better production by minimizing pest damage. In 117 experiments conducted by the International Rice Research Institute (IRRI) over a period of 15 years, nearly 87% greater rice yield is observed in insecticide-treated plots as compared to untreated-plots. The benefit-cost ratio increased from 3 to as high as 10(Gianessi, 2014a).

South Asian regions have diverse practices of Chemical application. In some parts of India, Carbofuran or Phorate granules are broadcasted in the wet nursery, 10 days after sowing, to prevent stem borers and gall midges in rice. However, soaking of sprouted seeds in 0.2% chlorpyriphos three hours before sowing is reported to be more effective against Gall midges. Soaking of seedling roots with 0.2% Chlorpyriphos for 12 hours is suggested to manage stem borer and gall midges at early growth stages of rice(Pasalu et al., 2004). Multiple tests in India have reported insecticides such as Carbofuran, Phorate, Cartap and Isazophos being safer to natural enemies than other spray formulations such as Monocrotophos and Chlorpyrifos. Triazophos and Acephate (spray formulations) were found to be safer to egg parasites of stem borer and predatory mirids and spiders(Lakshmi et al., 1998; Lakshmi, Katti, & Krishnaiah, 1997). A recent study revealed Rynaxypyr 20 SC @ 30 g a.i/ha to be the best chemical treatment for rice with least effect on natural enemies. Other than thatCartap hydrochloride 50 WP @ 375 g a.i/ha, Fipronil 5 SC @ 75 g a.i/ha were found to be highly effective against Yellow Stem borer. Thiamethoxam 25 WG @ 37.50 g a.i /ha, Buprofezin 25 SC @ 250 g a.i /ha and Dinotefuran 20 SG @ 40 g a.i /ha were found to be most effective against planthoppers. Fipronil 5 SC @ 75 g a.i/ha was found to be the best against gall midge(Seni & Naik, 2017).

Some false views have greatly affected the management of insect herbivores in rice ecosystems. These views include the idea that all insects typically have negative effects on crop health; herbivore disruption directly results in loss of yield, and rice yields are improved by insecticides. These beliefs have led to uncontrolled use of agrochemicals which have resulted in an unsustainable rice production system by fluctuation in production(Horgan, 2017). There have been incidents in the past where efforts to remove invasive species using insecticides have ended in disaster. Indigenous insects and natural enemies were wiped out in the act, creating additional troubles. An attempt to eradicate imported fire ants *(Solenopsis invicta and S. richteri)* led to US$200 million economic loss in the United States(Davidson & Stone, 1989). In other instances, insecticides destroyed both pests and natural predators, and sometimes pests returned, a phenomenon known as resurgence. This led to even higher population levels than earlier. Intensive use of pesticides not just disturbs the natural ecosystem but also hampers human lives.

Since the beginning of the Green revolution, over 800,000 people have lost their lives due to pesticide exposure in developing countries. This amounts to an average annual death of 20,000 individuals which is startling(Bhardwaj & Sharma, 2013). According to(Pimentel, 2009) the use of insecticides worth billions of dollars has failed to suppress the damage associated with insect pests which is still as high as 14% globally. Gatehouse (2002)pointed out growing concerns regarding the pesticides resistance developed by some insect pests due to their uncontrolled use. In Pakistan alone, over 500 arthropod species have developed resistance against the contemporary insecticides(Karim &Riazuddin, 1999). The use of pesticides has been discouraged in modern agriculture and the attention has been shifted towards environmentally friendly techniques(Gupta et al., 2019).

Some of the traditional methods seem more successful in terms of ecological sustainability and production as compared to the use of modern synthetic pesticides. So for sustainable crop production, beneficial aspects of traditional practices can be incorporated in the new insect pest management approaches.

5.4 Integrated Pest Management

There is a growing trend of crop losses despite the application of a number of control measures against pests(G. Dhaliwal et al., 2010). At present, Integrated Pest Management (IPM) is the preferred strategy for pest control which focuses on long-term prevention of pests and their damage through combined techniques. IPM was originally conceived as a reaction to a crisis led by overuse of synthetic organic pesticides(Barfield & Swisher, 1994).

The combined approaches in IPM include biological control, habitat alteration, modification of cultural practices, judicious application of chemicals and use of resistant cultivars. An important component of IPM has been the training of extension personnel and farmers to diagnose and monitor pest problems in the field and to use insecticides only when necessary(Gianessi, 2014a). The basic values of IPM include growing healthy crops by maintaining healthy soil, conservation of natural enemies, routine observation of fields, developing expert farmers and providing assistance in economic decision making(Gallagher et al., 2002).

Rice IPM extension has been evolving for decades in Asia. It has focused mainly on the incorporation of new techniques with existing management practices, participatory non-formal education and community learning(Matteson et al., 1994). Elimination of insect pests is difficult but the use of control approaches such as IPM helps in reducing their impacts and increasing the production(Myers et al., 1998).

5.5 Miscellaneous approaches

Developed countries like China, also the largest producer of rice, have been deploying advanced genomic strategies to keep the rice pests below the threshold. However, other less-developed nations have been relying on traditional methods(Ul Ane& Hussain, 2016).

Rapid developments in the field of genetic engineering have led to newer techniques for pest control with genetic modification. Progress in breeding programs has ushered successful exploitation of naturally occurring resistance genes available in the gene pool. Some improved rice varieties contain brown planthopper resistance genes which were introduced into them from pre-existing germplasms(Khush& Brar, 1991). Most of the plants grown in the pest prone areas develop host resistance naturally to one or more insects over a period. Host plant resistance is considered an effective, economical and pragmatic technique since it is compatible with the other methods of pest control(Pasalu et al., 2004). Molecular genetics holds the immense potential of transferring insect resistance genes from wild rice species and other species to *O. sativa* but much of it is left to be done(Heinrichs EA, 1994).

There is a well-documented history of safe application of Bt (*Bacillus thuringiensis*, a gram-positive soil bacterium) as successful biopesticides. A wide range of reports of δ-endotoxin gene(s) expression is found in several crops. Genes from *Bacillus thuringiensis* are transferred to the crop to express certain proteins that assist in pest management. Just a few insecticidal sprays are required for transgenic Bt crops, which not only saves time and expense but also reduces the health risks(Kumar et al., 2008). The use of Bt in Indica rice breeding line (IR58) showed up to 100% mortality of two of the most destructive rice insect pests of Asia namely stemborer and leaf folder(Wünn et al., 1996). Due to the limited supply of elite cultivars, their use has been restricted to certain areas and specific crops only(Kennedy, 2008).

Site-specific pest management is another promising approach which aids in decision making and emphasizing the area with economically high pest density. Spatial knowledge about pest distribution is used for this control approach(Park et al., 2007).

Modern techniques of pest management also include the use of fungal entomopathogens. Selective insecticides integrated with the fungal entomopathogens have shown promising results by inducing greater insecticides susceptibility. This helps in improving the control performance, reducing or delaying insecticide resistance by lowering the effective dose of insecticides. Though the exact mechanisms are not clear, reports suggest that such technique suppresses the enzymes responsible for inducing resistance, particularly mono-oxygenases and esterases(Ambethgar, 2009). Some insect-pathogenic fungi have been identified such as *Beauveria bassiana* and *Beauveria brongniartii* that can infect grasshoppers, locusts, thrips, aphids, flies among others. These fungi infect only insects but not the plants. This important trait has been exploited for controlling some important insect pests of rice(Copping, 2009). The technique is considered highly effective for few rice insects such as yellow stem borer, leaf folder, gall midges and Planthoppers but not much effective for others such as Rice hispa, Gandhi bug and Cutworm(Pathak, 1968).

Scientists working for the new advancements in pest control claim that the integrated control is insufficient and the use of pesticides is detrimental to the soil in addition to animal and human health. Lately, the field of nanotechnology has evolved significantly and it has been extended to pest controls in agriculture as well. Nanotechnology involves the formulations of pesticides and insecticides based on nano-materials, use of nanoparticle-mediated genes or DNA transfer to produce insect-resistant cultivars, preparation of biosensors that assist in remote sensing and so on. It has been promoted as an effective and harmless alternative for insect pest management(Rai & Ingle, 2012).

6. Conclusion

It is clear that there is no single solution to the insect pest problem in agriculture. Integrated control approaches should be followed for efficient management which includes the right combination of cultural, biological and chemical practices in addition to other modern techniques. Rice entomologists must work in close association with the scientists of other related disciplines. The knowledge of rice insect pests is very less in developing countries of South Asia. Comprehensive research is needed to understand the nature, distribution, etiology, epidemiology and the ecology of rice insect pests in addition to constraints and suitable control measures. Participatory approaches involving government agencies, researchers, extension workers, non-governmental organizations and farmers is necessary for successful management of insect pests. The current trends of chemical pesticides can be shifted to other alternative approaches like biological control or modified cultural methods for sustainable production. IPM in addition to other new approaches looks promising for the management of rice insect pests in South Asia, at present.

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