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Chapter –6

Pesticide Induced Resurgence of Rice Plant hoppers

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Planthoppers *viz.*, Brown planthopper (BPH), *Nilaparvata lugens* Stal; white-backed planthopper (WBPH), *Sogatella furcifera* Horvath and small brown planthopper (SBPH), *Laodelphax striatellus* Fallen are serious rice pests in Asia. The resurgence involves two mechanisms, the loss of beneficial insects and insecticide-enhanced planthopper reproduction. These complicated phenomena are not always solely caused by the removal of natural enemies, pesticide treatments also causes changes in the pest's behaviour, dispersal, development and fecundity indicating the resurgence. Types of pest resurgence found in modern cropping systems *viz.*, primary pest resurgence and secondary pest resurgence. Based on the time related process resurgence can be two forms of resurgence, acute and chronic. Acute resurgence is caused by traditional insecticides (organochlorines, organophosphates, carbamates, and pyrethroids) with a rapid resurgence in the F_1 generation. Chronic resurgence follows the application of modern pesticides, including fungicides and herbicides, with low natural enemy toxicity, coupled with stimulated planthopper reproduction. The chemical-driven syndrome of changes leads to a later resurgence in the F_2 or later generations. Pesticides also affect physiology and biochemistry of rice plant in different ways. Buprofezin, imidacloprid, and jinggangmycin reduce oxalic acid content in rice plants, increase amount of malondialdehyde in leaf blades and reduce sugar content in rice leaf sheath. Pesticides can increase BPH reproduction by influencing major hormone titers. Imidacloprid, triazophos (TZP) and deltamethrin treatments led to increased protein contents, particularly vitellogenin in BPH ovary and fat body. TZP, imidacloprid and deltamethrin treatments led to enhanced flight speed and distance. Males transfer seminal fluids which include sperm and accessory gland protein (AGP) to females via mating and AGPs influence female behaviours, including oviposition.

Introduction

The concept of pest resurgence was first reported in the early 1960s, caused mainly by insecticides that indiscriminately killed beneficial arthropods and target pests. Planthoppers *viz.*, Brown planthopper (BPH), *Nilaparvata lugens* Stal; white-backed planthopper (WBPH), *Sogatella furcifera* Horvath and small brown planthopper (SBPH), *Laodelphax striatellus*

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Fallen are serious rice pests in Asia. Resurgence an abnormal increase in pest population or damage following pesticides application often far exceeding the EIL. The resurgence involves two mechanisms, the loss of beneficial insects and insecticide-enhanced planthopper reproduction. These complicated phenomena are not always solely caused by the removal of natural enemies, pesticide treatments also causes changes in the pest's behaviour, dispersal, development and fecundity indicating the resurgence (Hardin *et al.,* 1995*).* Pesticide-induced resurgence involves ecological and physiological factors. Pesticides also affect physiology and biochemistry of rice plant in different ways. Insecticide resistance and insecticide-induced resurgence are closely related, and resultant outcome is pest outbreak or resurgence. The resurgence may be induced via alterations of resistant or nutritious substances in treated host plants, possibly including allelochemicals due to alterations in crop plant physiology. Pesticide-induced rice susceptibility may benefit BPH feeding, survival and reproduction

Types of Resurgence

Types of pest resurgence found in modern cropping systems *viz*., primary pest resurgence and secondary pest resurgence (Dutcher, 2007). **A). Primary pest resurgence** occurs when the target insect or mite population responds to an insecticide treatment by increasing to a level at least as high or higher (Hardin *et al*., 1995) than in untreated control or higher than the population level observed before the treatment. The resurgence may occur after the first application or after several applications of the insecticide. Pest population outbreaks can be caused by many factors but pest resurgence occurs after a treatment of the crop with a chemical targeted at the pest population that is intended and expected to control the targeted pest. **B). Secondary pest resurgence** replacement of a primary pest with a secondary pest or a secondary pest outbreak occurs when a non-target, but injurious, pest population increases in a crop after it is treated with a pesticide to control a primary pest population (Hardin *et al*., 1995). The increase is an unintended and unexpected consequence of the pesticide treatment. A: Pesticide is applied to suppress pest 1 but also kills natural enemies that feed on pest 2 and B: Pest 2 free from regulation of NEs then pest 2 becomes a major problem.

Framework of Forms of Resurgence

Based on the time related process resurgence can be two forms of resurgence, acute and chronic. Acute resurgence is caused by traditional insecticides (organochlorines, organophosphates, carbamates, and pyrethroids) with rapid resurgence in the F_1 generation. Simultaneously, at sublethal doses, most insecticides stimulated planthopper reproduction through a variety of physiological and molecular mechanisms. Chronic resurgence follows application of modern pesticides, including fungicides and herbicides, with low natural enemy toxicity, coupled with stimulated planthopper reproduction. The chemical-driven syndrome of changes leads to later resurgence in the F_2 or later generations (Wu *et al*., 2019).

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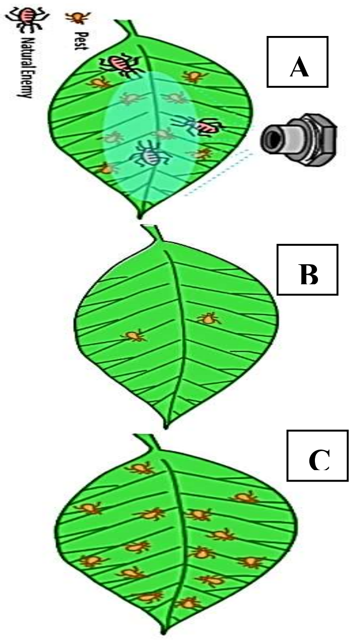

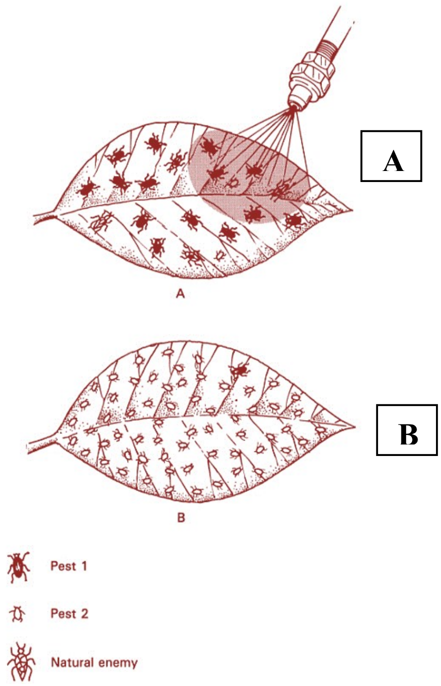

Fig.1: **A-** Both majority of Pests & Natural enemies (NEs) were killed, **B-** Plant pests re-colonize first and **C-** Pest unrestrained by NEs then increase to a level greater than A

Fig.2: **A-** Pesticide is applied to suppress pest 1 but also kills natural enemies that feed on pest 2 and **B-** Pest 2 free from regulation of NEs then pest 2 becomes a major problem.

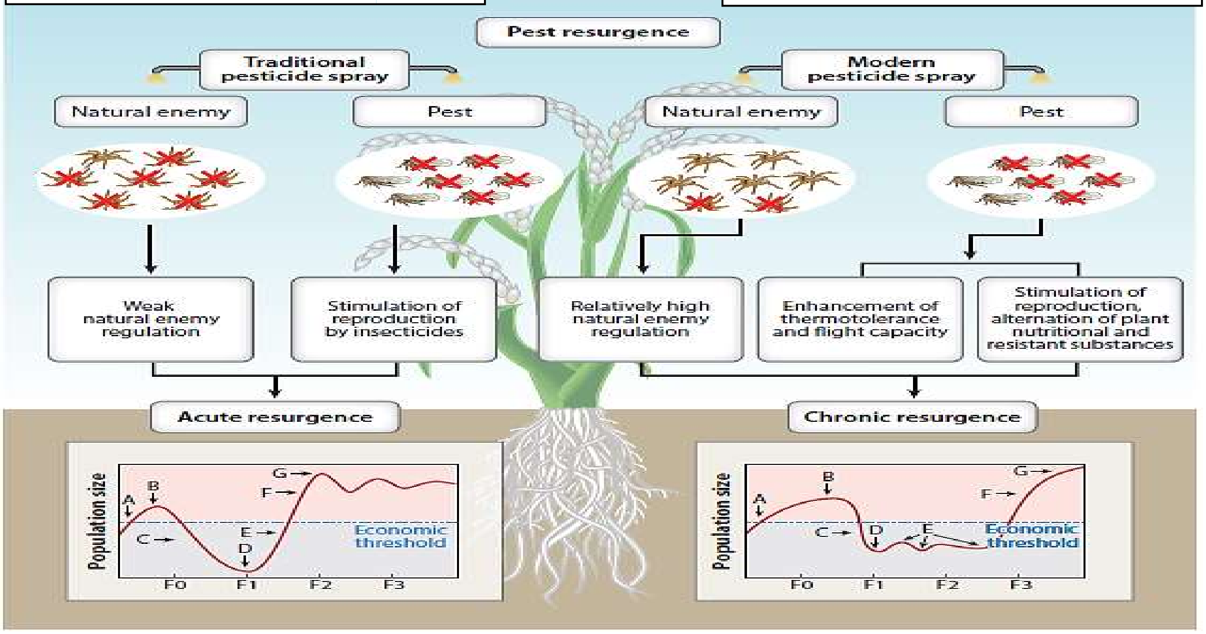

Fig.3: Diagrammatically framework of acute and chronic planthopper resurgence.Acute resurgence is linked to rapid planthopper population growth in the absence or weakening of natural enemies following traditional insecticide applications.Chronic resurgence after application of modern pesticides is characterized by delayed population growth due to the presence of natural enemies.At point **A**,the population exceeds the economic threshold; at

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point **B**,pesticide is applied; at point **C**,there is rapid population decline due to pesticides; at point **D**,the lowest population level before reproduction starts; at point **E**,reproduction leads to population growth,which is unchecked in acute resurgence but limited by natural enemies in chronic resurgence; at point **F**,there are large resurgent populations; and at point G,severe economic losses occur.

Population Characteristics of Planthopper Resurgence

After applications of insecticides, planthopper populations were **suppressed for approximately 3 days,** then rapidly rebounded. Patterns of BPH & WBPH population size changes after application of Triazophos, **A).** A continuous population increase to a peak followed by a decline, **B).** An immediate decline and **C).** A decline followed by a higher peak and then a decline. Sublethal Nitenpyram concentrations led to increased macropterous/brachypterous BPH ratios. **Symptoms of resurgence population such as** larger number of planthopper individuals with flight-capability, increase theromotolerance, increase body weight, increase valvula length, stimulate reproduction and hopper burn in rice field.

Resurgence factors of planthoppers

A. Influence of pesticides on physiology and biochemistry of rice plants

Oxalic acid (OA) acts in rice resistance to BPH, but triazophos and imidacloprid, lead to reduced OA content in rice which favourable for BPH feeding. Buprofezin, imidacloprid, and decamethrin lead to higher reduction of sugars and free amino nitrogen which benefits to planthoppers. Concentrations of the insect inhibitory neurotransmitter γ-aminobutyric acid in rice plants were reduced following treatments with the herbicides, butachlorebtazone, the antibiotic jinggangmycin (JGM) (Cheng *et al*., 2012). Cytokinins, including zeatins riboside (ZR), act on cell division, elongation and influence the intensity and direction of photosynthate flows. ZR content in rice leaves decreased significantly three days after separate foliar sprays & rice root treated with buprofezin, imidacloprid, JGM and triazophos. The level of malondialdehyde (MAD) in rice leves and sheath increase by the application of imidacloprid that facilitate to BPH feeding (Qiu *et al*., 2004).

B. Pesticides influence rice gene transcription profiles

225 genes that were differentially expressed after an imidacloprid treatment; 117 were up-regulated, and 108 were down-regulated. Of these, specific expression of genes encoding plant lipid transfer protein, lignin peroxidase, and flavonol-3-o-methyl transferease was changed. This type of change responsible for the imidacloprid induced rice susceptibility to BPH, which inflicted more damage on treated than control rice plants. (Cheng *et al*., 2012).

C. Pesticide-induced susceptibility to planthoppers

PIS facilitates planthopper feeding, survival, and fecundity and may there by promote resurgence**.** Applications of bisultap, imidacloprid, JGM, butachlor, bentazone, metolachlor, bensulfuron-methyl, acetochlor, are led to increased damage level of rice plant infested by

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Planthoppers. Repeated pesticide applications extended the duration of PIS, which, again, may facilitate planthopper resurgence (Wu *et al*., 2001).

D. Impacts of pesticide application on natural enemies of planthoppers

Agricultural chemicals challenge natural enemies in **two ways:** (1) by killing some individuals and, in surviving individuals and (2) by sharply reducing their abilities to search for and locate pest eggs, larvae, pupae, and adults (Wu *et al*., 2019).

Table 1: list of pesticides it's effect on natural enemies

Natural enemies	Pesticides	Effect	References
Cyrtorhinus lividipennis	Butachlor, Disopropyl S-benzyl phosphorothiolate, Triazophos and Deltamethrin	High mortality, Reduction in prey consumption	Cheng *et al.*,1999; Xu *et al.,*2000
Lycosa pseudoannulata	Chlorpyriphos, Abamectin,	More lethal	Cheng *et al.,*1999
Pirata subpiraticus	Bisultap, Methanidophos and Buprofezin , Triazophos and Pymetrozine , Butachlor, Oxyfluorfen, Oxadiazon, and Metolachlor	Functional response less to prey , Negative effect on egg development	Li *et al.,* 2000
Anagrus nilaparvatae	Pymetrozine , Imidacloprid, Triazophos and Deltamethrin	Reduction in foraging capacity, Sensory response, Survival & parasitism	Liu *et al*.,2010

Triazophos and pymetrozine have a serious negative effect on egg development of the *P. subpiraticus*. Yolk granules in eggs showed a loose arrangement, and some eggs remain empty.

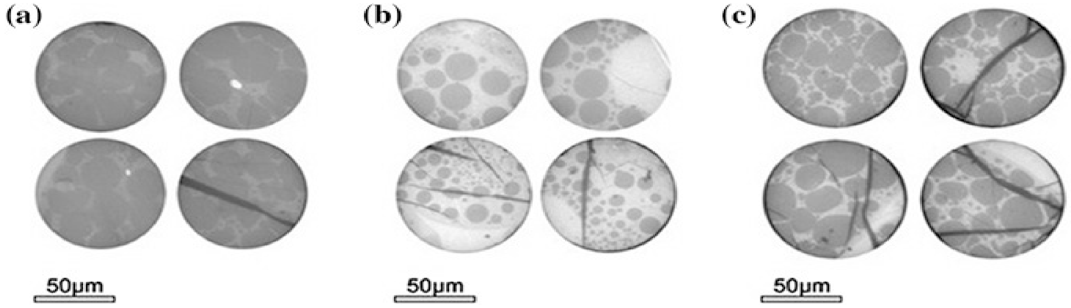

Figure: Comparisons of arrangement of yolk granules of egg of *P. subpiraticus* **(a) Untreated control, (b) Pymetrozine treated eggs c) Triazophos-treated eggs (Xu *et al*., 2000).**

Hormoligosis

A dose response phenomenon which occur in pest populations due to exposed to sublethal doses of pesticides. This can cause an increase in fecundity (physiological hormoligosis) or oviposition behaviour (behavioural hormoligosis) of the pest leading to a significant increase in its abundance. A low dose elicits a stimulatory response and a high dose elicits an inhibitory response (Calabrese & Baldwin, 2003). In these cases, the dose-response to the chemical treatment is an ∩-shaped curve and not linear or log-linear. That is, starting at a response of zero and a dose of zero (control level) and moving to higher doses the response is initially stimulatory and then inhibitory. The reproductive rate of the brown planthopper increases when it is exposed to low doses of either deltamethrin or methyl parathion (Chelliah & Heinrichs, 1980*).*

Table 2; Effect of pesticides on reproduction of rice planthoppers

Pesticide	BPH	WBPH	SBPH
Abamectin	+	×	×
Acetochlor	+	×	×
Bentazone	+	×	×
Bisultap	+	×	×
Butachlorebtazone	+	×	×
Carbamate	+	×	×
Carbendazim	+	×	+
Carbofuran	+	×	×
Carbaryl	+	×	×
Chlorpyrifos	+	×	×
Cyclosulfamuron	+	×	×
Daizinon	+	×	×
Jinggangmycin	+	+	-
Methanidophos	+	+	+
Triazophos	+	+	+

A plus sign (+) represents stimulation, a minus sign (−) represents suppression of reproduction & a multiplication sign (×) represents unclear results.

Planthoppers reproduction associated factors

A. Physiological and biochemical effects of pesticides on planthopper reproduction

Juvenile hormone (JH) is a pleiotropic hormone with many actions in juvenile (i.e., regulating developmental out comes of molts) and adult (i.e., promoting ovarian development) insects. Circu- lating JH titersare regulated by factors that increase JH production in corpora allata and enzymes that catabolize JH, such as JH esterase.TZP and deltamethrin treatments led to increased circu- lating JH-III titers in BPH females over 1–3 days postemergence (PE). The increased hormone titers redue to reduced levels of active JH esterase during the first three days PE. (Xu *et al*., 2016). JGM treatments led to increased JH titers (by approximately 45–50%) in BPH females over two days PE, and they decreased 20-hydroxyecdysone(20E) titers by30–36%. Agricultural chemicals can increase BPH reproduction by influencing major hormone titers. Although JH influences reproductive output, the underlying mechanism is related to increased availability of energy resources to support energy-intensive reproduction. Imidacloprid, triazophos, and deltamethrin treatments led to increased protein contents, particularly vitellogenin in BPH ovary and fat body. Foliar spray and topical application of triazophos and jinggangmycin foliar spray significantly increased fat body and ovarian protein levels. Amounts of unfractionated lipids, fatty acids & soluble sugar were higher in adults that developed from nymphs treated with various concentrations of deltamethrin, triazophos, and imidacloprid (Hu *et al*., 2010; Zhu *et al.*, 2014).

B. Flight muscle associated with pesticide induced BPH reproduction

Planthopper migratory capacity and distance are closely related to resurgence. Transmission electron microscope (TEM) studies shows that the diameters of female muscle myofibrils are larger at day one (by 31%) and two (by 21%) post emergence following triazophos treatment. Similarly, sarcomere lengths and mitochondrial volumes were larger when treated with triazophos. Triazophos, imidacloprid, and deltamethrin treatments led to enhanced flight speed and distance. We infer that exposure to some insecticides can increase overall migratory potential (Wan *et al*., 2013).

C. Analysis of Gene Functions

Hydroxysteriod dehydrogenase-like protein 2 and long chain fatty acid coenzyme A ligase act in the carbendazim and triazophos-induced SBPH reproductive increases (Zhang *et al*., 2018). Fatty acid synthase (FAS), adipose triglyceride lipase, acetyl-CoA carboxylase (ACC), and EST-1 participate in jinggangmycin-induced stimulation of BPH reproduction (Jiang *et al*., 2016). Acyl-coenzyme A oxidase mediates triazophos-induced BPH reproductive stimulation (Liu *et al*., 2016).

D. Pesticides enhance accessory gland proteins

Males transfer seminal fluids, which include sperm and accessory gland protein (AGP) to females via mating & AGPs influence female behaviors, including oviposition. Insecticide-treated males transferred more AGPs to females, where they contribute to enhanced egg production. Treating third-instar BPH nymphs with 25 and 50 ppm triazophos & deltamethrin led to roughly double the amounts of AGPs in the adult males prior to mating (1 and 2 days PE) (Wang *et al*., 2010).

E. Proteomic Analysis of male accessory gland

TZP-treated unmated BPH males versus untreated unmated males & TZP-treated unmated males versus treated mated males showed 16 differentially expressed proteins in the treated males compared to their untreated counterparts, 10 increases and 6 decreases. Act-5C Protein, which acts in flight muscle isoforms, sperm individualization, and mushroom body development, was upregulated 19-fold. Spermatogenesis associated protein 5 and testis development protein NYD-SP6 were upregulated 3.1 and 5.5-fold, respectively. These proteins are involved in spermatogenesis, & they enhancing male contributions to BPH reproduction & increased fecundity (Ge *et al*., 2011).

Conclusions

Balance should be established between the chemical controls and biological controls against rice planthoppers, because many insecticides showed high toxicities against natural enemies. We mention above that JGM & carbendazm (CBM) application to control rice disease should be avoided in the presence of BPH populations because JGM & CBM stimulates BPH reproduction. Triazophos, deltamethrin, bifenthrin, cypermethrin application, enhances reproduction of planthopper species & also kills natural enemies or reduces their biological control efficacy. Triazophos, imidacloprid, and deltamethrin treatments led to enhanced flight speed, distance and male accessory gland proteins. Resurgent populations are influenced by interactions of insecticides with other factors, such as rice variety and timing and dosage of fertilization.

Future prospects

Further research should be carried out on the physiological and molecular mechanisms. The results of such work needs to be incorporated into resurgence models that link molecular mechanisms to ecological effects. Continued research into planthoppers biology is needed. How the mixtures of insecticide and fungicide influence the planthopper resurgence behaviour further can be exploited.

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