Host Plant Resistance: A Key Component in Mitigating Rice Gall Midge Infestation (*Orseolia oryzae*)

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Rice occupies an important place in Indian agriculture and is the major food source for more than 70 per cent of the world's population. Insect pests are the limitation for rice production, among them the Asian rice gall midge (ARGM), *Orseolia oryzae* (Wood-Mason) (Diptera: Cecidomyiidae), is considered as national pest. Since from the beginning of the 20th century, the gall midge is major threat to paddy cultivation in coastal Karnataka and has acquired the status of major pest in Cauvery command area and started spreading towards adjacent districts (Mamathad *et al.,* 2020).

The incidence of Asian rice gall midge was up to 65.00 per cent with silver shoot range from 8.80 to 19.20 per cent at different locations of coastal Karnataka when compared to southern parts of Karnataka, where the incidence was in between 6.50 to 10.25 per cent silver shoot. For every 1 per cent increase in gall midge incidence leads to 0.5 per cent yield loss (Israel *et al.,* 1959). This pest is usually endemic to coastal areas, but in the previous year there was a severe outbreak of Asian Gall midge in Kalyana Karnataka region occurred during *kharif* 2020 for the first time with the yield loss upto 25-35% in the TBP Command area (Hurali *et al.*, 2020).

Since this pest is an internal feeder which becomes difficult to control through insecticides. Along with insecticides we should also choose the tactic which is compatible to all other control tactics and can manage the pest successfully *i.e,* developing the resistant varieties based on resistant factors which may found in the host plant by knowing the insect biology, host response to the pest attack and their interaction.

Biology of the Asian rice gall midge and damaging symptoms

Asian gall midge (AGM) has four stages of life *viz.,* egg, maggot, pupa and adult. Eggs are laid on plant surface near the midrib of leaf without discretion as hot plant and hatch on 4th day after oviposition under humid environment. Neonate maggot crawl in the thin film of water on the surface leaf sheaths to enter the space between these. This stage is critical and success depends on humidity and rainfall. AGM has three instars as maggots prior to pupation. First two instars feed actively while feeding ceases in the third instar. Maggot duration lasts about 8-10 days while pupal duration is about 10-12 days depending on the ambient temperature. AGM pupa is exceptionally active and wriggles upwards in the elongated gall cavity and drills an exit hole at the apex and slightly protrudes out to facilitate eclosion and adult emergence. The adult period lasts about 1-2 days. Male adults emerge one day before the emergence of female and immediately mating occurs. Usually field ratio of female and male is 3:1. The abdomen of the male is yellowish brown with the size of 3mm length, 23 antennal segment and survive for 23-30 hrs. In contrast the female abdomen is bright red in colour with the size of 4 mm length, 13 antennal segment and survive for 48-78 hrs.

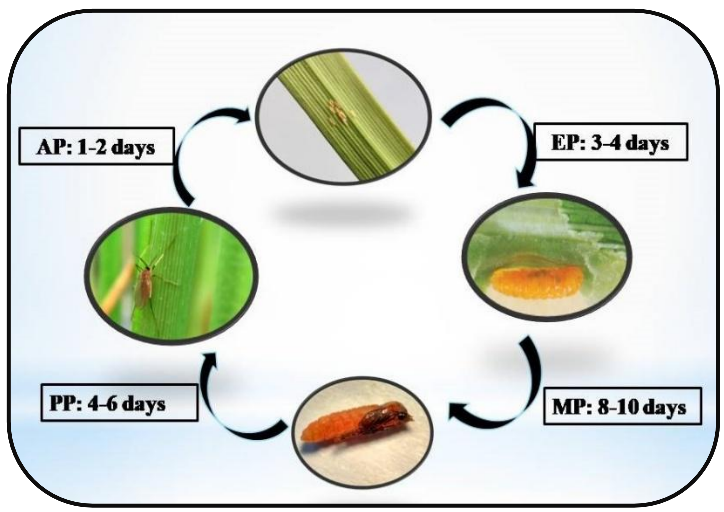


Fig. 1. Biology of Asian gall midge, *Orseolia oryzae* (Wood-Mason)

At the feeding site, the host cells enlarge and show hypertrophy and hyperplasia establishing a nutritive tissue for insect feeding due to the salivary secretion of the maggot contains an active substance called "Cecidogen" that leads to formation of "silvery shoot". Infestation starts from seedbed to booting stage. Maggot can develop only on the growing primordia (stage when the panicle is being formed) and cannot survive on a crop beyond the vegetative stage. While several maggots reach the meristem, soon one of them predominates while others are pushed out of the gall chamber that is built around the active maggot. Rest of the maggots survives without feeding for some time and move to the new tillers that are actively produced by the plant. Gall is the modified leaf sheath that turns tubular in shape and bears vestigial leaf blade at the top. This change arrests further differentiation of the tillers and formation of reproductive structures leading to yield loss (Bentur *et al.,* 2016)

Fig 2: Silver Shoot symptoms in main field and nursery

Host plant – Insect interactions

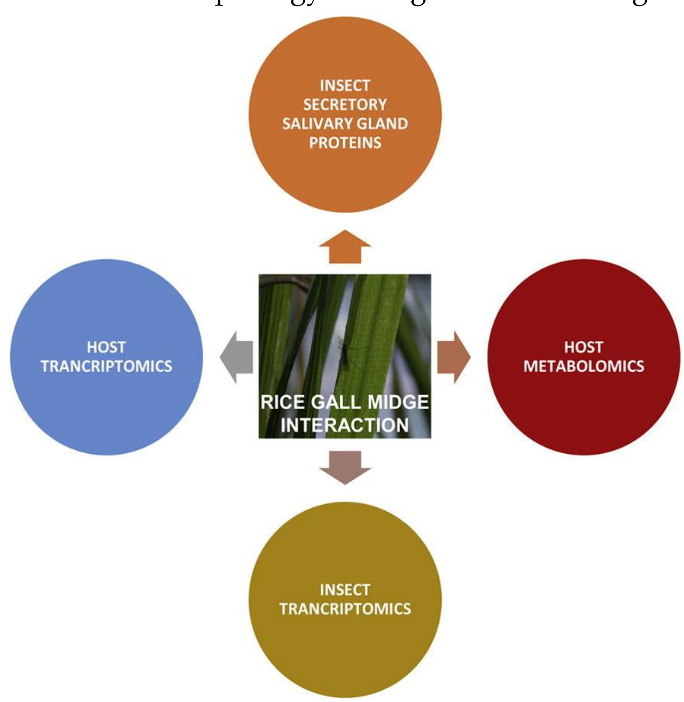
The interactions of herbivorous arthropods with their plant hosts are complex and multifaceted, even when they take place in the simplified ecosystems characteristic of agriculture. The overall process by which an herbivore makes use of a plant usually involves a number of phases:

Searching phase in which the herbivore moves, often in response to visual and odour cues, from a location lacking a host-plant to a potential host;

Contact evaluation phase mediated by an expanded set of visual, physical, and chemical cues from the plant;

Host utilization phase in which the performance of the herbivore is influenced by interacting suites of nutrients, toxins, digestibility reducers, and other factors in the plant (Heinrichs, 1994)

At each step in this process, the herbivore interacts not only with the potential host plant but also directly or indirectly with other organisms at the same trophic level, such as competing herbivores, with organisms at different trophic levels, such as predators and parasitoids, and with microorganisms. Evolution of plant and phytophagous insects is directed towards their ability to either avoid or suppress or reprogram host metabolic machinery to favor their survival. Among the phytophagous insects, gall formers or gall midges are exemplars in evading or maneuvering the planet defense metabolism. They divert host nutrients for their feeding and orient hormone signaling to reconfigure the host cell morphology leading to formation of galls.



a. Compatible Interactions

Two distinct interactions are noted when GM attempts to feed on a rice plant. When the rice variety is susceptible, the insect establishes in the plant and a gall is formed. In this case, the insect is able to complete its development and emerge from the plant as an adult fly through a hole in the gall. Although morphological changes occurring during gall development have been described, no detailed studies are available on biochemical changes during this process. A chemical called "cecidogen" secreted from the insect salivary gland is implicated in gall formation. Similarities in tissue proliferation following application of low doses of Indole acetic acid (IAA) and infestation by gall midge suggest involvement of plant growth regulators in gall formation. Higher IAA and tryptophan content are observed in gall tissue compared with healthy plants. Saliva in certain gall-forming insects contains IAA, which acts a gall inducer. Polyphenol oxidase (PPO) is yet another component of the saliva of the insect. The complex role of phenolic compounds and phenol oxidases is fundamental to gall development. Cell conditioning precedes gall induction. The gall tissue acts as a physiological sink provides the growing insect with nutrients.

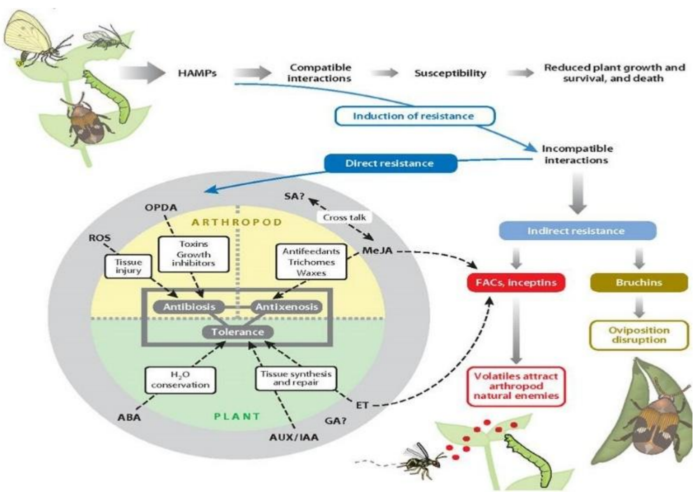


Fig 3: Interaction between plant and insects

b. Incompatible Interactions

During an incompatible interaction, when the variety is resistant, the insect fails to establish and the plant suffer little damage. This interaction is closer to plant-pathogen interaction rather than plant-insect interaction as it exhibits gene-for-gene interaction between plant R and insect avr genes. The mechanism of defense against insects is less understood. Recently, using GC-MS based metabolic profiling, several metabolites such as fatty acids, volatile alkenes, sterols, phenolic compounds were identified as resistance features during rice-gall midge interaction (Agarwal *et al.,* 2014). These resistance features were common to both types of incompatible interaction that either manifested with or without HR. These classes of compounds are known to play a role in plant defense against insects.

Host Plant Resistance

This concept is given by R. H. Painter (1951). Host plant resistance refers to "the heritable qualities of a cultivar to counteract the activities of insects so as to cause minimum per cent reduction in yield as compared to other cultivars of the same species under similar condition''. He has categorized the resistance into dichotomous and trichotomous framework. Under trichotomous he included mechanisms of host plant resistance. Resistance can also be divided into 'constitutive' or 'inducible' and 'direct' or 'indirect' sub-categories.

- ✓ **Constitutive plant resistance** is resistance that is expressed regardless of the prior history of the plant, whereas inducible resistance is resistance only expressed, or expressed to a greater extent, after prior injury (i.e. expression of inducible defenses is contingent on prior attack, whereas constitutive defenses are not).
- ✓ **Direct plant resistance** refers to those plant traits that have direct (unmediated) effects on herbivore behaviour or biology. **Indirect plant resistance**, in contrast, depends for its effect on the actions of natural enemies.

Mechanisms of Host Plant Resistance

3 categories of mechanism is given by R. H. Painter

a. Antixenosis (Non-acceptance)

Kogan and Ortman (1978) proposed the term antixenosis to replace nonpreference it is defined as complex of plant characteristics which prevent insects from approaching, landing, settling, feeding or ovipositing; it affects the behavior of insects (altered number of insects landing or number laying eggs); has been termed non-acceptance.

Eg: Absence of asparagine production – Brown plant hopper

Leaf hairiness – Cereal leaf beetle

Stem hardiness – Wheat stem sawfly

Trichomes in cotton – Whitefly

Waxiness in cabbage – Diamond back moth

In polyphagous pest, *Helicoverpa armigera* – antixenosis not be a effective mechanism of resistance.

b. Antibiosis

This is a mechanism of resistance that includes those adverse effects on the insect life history which result when a resistant host plant is used for food. The effects measured may be in the form of death of the early instars, small size or low weight, abnormal longevity, low food reserves, less fecundity, death in the prepupal stage, and abnormal behavior.

Eg: DIMBOA – European corn borer

Saponins – alfalfa aphid

Low level of amino acid & increased level of sugar – Pea aphid

c. Tolerance

The term refers to withstand or recover from damage caused by the insects. When a tolerant variety is attacked by insect pest to the same degree as a susceptible variety, but at the same level of infestation, tolerant variety produces a larger yield than susceptible.

Eg: Maize – Western corn root worm – In this case plant repair and replace the roots damaged by the root worm.

d. Ecological resistance

Also called as apparent resistance or pseudo resistance and it is not a heritable character.

- Host evasion means the host passes through the most susceptible stage quickly before the peak incidence. Eg: Early maturing varieties
- Induced resistance defined as temporarily increased resistance resulting from condition of plant environment. It is transient and non heritable. Eg: K application, Harpin (Protien) which binds a specific receptors of host plants activates natural defenses of host.
- Host escape is the lack of infestation due to inadequate pest load.

Biotypes

HPR is considered to be one of the most practical solutions to insect pest problems. However, the tremendous diversity and inherent capacity of insect species can cause severe infestation even on resistant genotypes. Hence, insect populations are thus dynamic and capable of defeating host plant resistance. The term biotype is an infraspecific category referring to insect populations of similar genetic composition for a biological attribute. The biotype populations may be partially and temporarily sympatric (coincident), allopatric or parapatric with other compatible populations, but differ in one or more biological attributes. Biotypes are usually identified based on host or food preferences, behaviour, genetic composition and variation, physiological responses to physical changes and stresses in the environment, reproductive analyses (fecundity and fertility), diurnal or seasonal activity patterns, migration and dispersal tendencies, pheromone differences and disease vector capabilities.

a) Evolution of Insect Biotypes

Biotypes represent the evolutionary transitional forms of insect populations in speciation. The evolution of biotypes is a complex process governed by the interactions of the genotypes of pest populations and cultivated varieties as well as heterogeneities of their habitats. The host system induces an abrupt change on the insect's survival locus (loci) conferring an advantage of fitness on the surviving genotypes. Other plausible alternative explanation is that the insect populations are preadapted and the best fitted genotypes are expressed depending on the existing environmental conditions. Also, the possibility of development of pest biotypes through mutation or their spread through migration

Biotypes develop when antibiosis is the mechanism of resistance. They seldomly develop when tolerance or non-preference is the mechanism of resistance inherent in the plant. When antibiosis is the mechanism, then the selection pressure in the form of a resistant crop variety resulted in the death of most of the insects. The virulent variants within the population that survived interbreed to form the population of a new biotype; the resistant plant may then become susceptible. Biotypes, therefore, are natural products of a survival mechanism for the perpetuation of insect species selected out by a resistant cultivar grown in areas where exposure to the insect is common. Diversification and specialization of an insect pest species into biotypes thus enable it to keep pace with the evolution and escalation of the defences of the host plant through natural selection or by man's manipulation of host plant's genome through breeding techniques (Saxena and Barrion, 1987). The host specific biotypes of insect pests evolve through natural selection acting upon the genetic variations within the species.

Knowledge of occurrence of gall midge biotypes is a prerequisite to design crop improvement programs for incorporating pest resistance. To slow down the process of biotype selection, crop cultivars with broad genetic bases are needed. On the other hand, knowledge of genes and pathways involved in insect virulence and evolution of biotypes is strongly needed. Better understanding of insect virulence genes, pathways involved in insect virulence, and interaction of virulence genes with host genotypes may be helpful in delaying the evolution of resistance-breaking evolutionary transients in target insect population. Bentur and Kalode, (1996) reported two types of resistance reactions exhibited by resistant rice plants in response to gall midge feeding; HR+ type is characterized by symptoms of tissue necrosis at the site of maggot feeding and HR- type in which no tissue necrosis occurs, but the insect mortality is observed. Of the 11 known R genes, only Gm1 and Gm8 confer HR- type resistance, while the other 9 genes provide HR+ type resistance.

Conclusion

Plant resistance is an ideal management tactic which is usually simple and inexpensive for farmers to implement and compatible with other tactics. To develop effective resistant varieties against the pest there is a need to identify and utilize new resistance genes. Due to extensive use those resistance cultivars, biotype shifts may occur. Hence consideration must be given to identifying appropriate breeding methods to cope with the problems. Alternatively, gene pyramiding and gene deployment with Marker Assisted Selection (MAS) is being considered as a viable option for achieving durable gall midge resistance in rice.

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