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Integrated Pest Management Package for Leafhoppers and Planthoppers (Insecta: Hemiptera) in Paddy Fields

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Abstract

The aim of the present article is to shed light on the current status, species composition, abundance, habitat affinities, distribution patterns of leafhoppers and planthoppers along with their integrated pest management (IPM) in the rice growing regions. Leafhoppers and planthoppers such as white rice leafhopper (*Cofana spectra* Distant), brown planthopper (*Nilaparvata lugens* Stal), whitebacked planthopper [*Sogatella furcifera* (Horvath)], green planthoppers [*Nephotettix nigropictus* (Stal)] and *Nephotettix virescens* (Distant), and lophopid leafhopper (*Pyrilla perpusilla* Walker) are sap feeders from the xylem and phloem tissues of the plant. Both adults plus nymphs of leafhoppers and planthoppers have piercing mouthparts that they insert into the leaf blades and leaf sheaths of rice plants to suck sap, and egg laying by hoppers blocks the water and food channels inside the plant. Severely damaged plants become dry and take on the brownish appearance as these have been damaged by fire, hence termed as hopper burn and at this level, crop loss may be 100%. The Integrated Pest Management (IPM) philosophies are growing a healthy crop by conserving of natural enemies; observing the field regularly (e.g., water, plants, pests and natural enemies); and farmers should strive to become experts. Simultaneous planting and cropping of rice over large areas; rotating rice with non-host crops, or fallowing between two rice crops; selective elimination of suitable hosts and habitats (sanitation); plant spacing to allow some sunlight to reach basal portion of plant; proper water management i.e., raising water level, or draining; early planting of short-season rice; integration of resistant varieties; and judicious use of pesticides are key component in IPM. Host plant resistance has served as a key component in IPM programs and in the development of sustainable rice creation systems, widespread adoption of such varieties has helped to stabilize rice production. The overall assessment indicates that resistance in rice to the hoppers is shown by the combined influence of non - preference by the hoppers for feeding, orientation and oviposition coupled with antibiosis. However, to accomplish this, decision-making must always take into consideration both the costs of inputs and the ecological ramifications of these inputs.

Keywords

Rice Pests, *Oryza sativa*, Pesticide, Planthopper, Leafhopper, Feeding Damage

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1. Introduction

Rice, is an annual grass of family Gramineae, and belongs to the genus *Oryza*, which includes twenty wild species and two cultivated species, *O. sativa* (Asian rice) and *O. glaberrima* (African rice). The *O. sativa* is the most commonly grown species throughout the world today, but in Asia, it is differentiated into three subspecies based on geographic conditions; *Indica* (tropical and subtropical varieties grown throughout South and Southeast Asia and southern China), *Javanica* (awned and awnless rice with long panicles and bold grains growing alongside of Indicas in Indonesia), and

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Japonica (short and roundish grained varieties of temperate zones of Japan, China and Korea). The diversity and community structure of arthropods in an organic double-cropped rice ecosystem have collected 114 species of arthropods, which consist of including 58 species of spiders, 16 species of predatory insects, 25 species of phytophagous insects, 15 species of neutral or other insects, in early season crop. Rice is attacked by several insects; some of these pests are of national significance, while others are pests of regional significance. Insect pests like gall midge (*Orseola oryzae*), white backed planthopper (*Sogatodes oryzae*), white backed planthopper (*Sogatella furciferra*), yellow stem borer (*Sciropophaga insertulas*), leaffloder (*Cnaphalocrosis medinalis*) and brown planthopper (*Nilaparvata lugens*) are pests of national significance [1].

Indiscriminate intensification of insecticides use, however, involves a number of serious hazards that can be hazards for pesticide applicators, hazards for consumers, environmental hazards and resistance of target pests [2]. Thus, integrated pest management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques [3, 4, 5, 6, 7].

2. Leafhoppers and Planthoppers

In general, the leafhoppers and planthoppers (order Hemiptera) are sucking insects which remove plant sap from the xylem and phloem tissues of the plant. The leafhoppers (family Cicadellidae) attack all aerial parts of the plant, whereas the planthoppers (family Delphacidae) attack the basal portions (stems). Severely damaged plants dry and take on the brownish appearance of plants called hopper burn. These insects are severe pests in rice where they not only cause direct damage by removing of sap, but also act vectors of serious rice virus diseases, such as rice tungro virus transmitted by the green leafhopper *Nephotettix virescens*, and grassy stunt virus transmitted by the brown planthopper *Nilaparvata lugens*. Hopperburn is similar to the feeding damage or bugburn caused by the rice black bug, but to confirm hopperburn caused by planthoppers, check for the presence of sooty molds at the base of the plant [8]. Planthoppers are a large group of small herbivorous insects, most of which live on monocotyledons by feeding on phloem sap. A field survey of the overwintering planthoppers associated with the rice agro-ecosystemss revealed 22 species of planthoppers collected and identified, with one species representing the subfamily Stenocraninae and the other 21 species in Delphacinae incuding Nycheuma cognatum (Muir), *Peregrinus maidis* (Ashmead), and *Pseudosogata vatrenus* (Fennah). Abandoned rice paddies with dense Poaceae grasses (Poaceae) are the most favorable overwintering habitat [9]. Among them, *Nilaparvata lugens* (Stal), *Sogatella furcifera* (Horvath), and *Laodelphax striatellus* (Fallen), are devastating pests of rice in tropical and temperate Asia [10].

Amongst sixty-five species of planthoppers representing associated with rice agroecosystems are reported in tropical Asia. Of the total, most notably are the leafhoppers such as *Cofana spectra* (white rice leafhopper) (Hemiptera: Cicadellidae), *Pyrilla perpusilla* (leafhopper) (Hemiptera: Lophopidae), *Nilaparvata lugens* (brown planthopper, and *Sogatella furcifera* (whitebacked planthopper) (Homoptera: Delphacidae), the green planthopper *Nephotettix nigropictus* and *Nephotettix virescens* (Homoptera: Cicadellidae). This article provides summaries and analyses of the key works and issues, and delivers details on management approaches. Today, three major species of rice planthoppers (brown planthopper, whitebacked planthopper, and small brown planthopper) have been noted in rice [11].

The Fulgoroidea, Cicadellidae and Membracidae are the most likely families in which Viruses transmission vectors are found, because they feed primarily on the phloem [12, 13, 14]. Two plant viruses are known to be transmitted in a semipersistent manner by leafhoppers. One is waikavirus-Rice tungro spherical virus (RTSV) and another badnavirus-Rice tungro bacillform virus (RTBV). These viruses are located mainly in phloem tissues of their host plants [15]. Following species of hoppers are observed causing severe damage to rice plants:-

2.1. White-backed Planthopper *Sogatella furcifera* (Horvath) (Hemiptera: Delphacidae)

The adult hopper is 3.5-4.0 mm long, body creamy white with the mesonotum, abdomen black dorsally and the legs are ochraceous brown. There is a conspicuous black dot at the middle of the posterior margin of each forewing, which meets when the forewings come together. Macropterous males and females and brachypterous females are commonly found in the rice crop, whereas brachypterous males are very rare. The average fecundity of 132.8 eggs/ female in cluster of 5 to 30 eggs is noted when hopper reared on wheat seedlings. The highest numbers of eggs are laid on leaf sheath of plants followed by midrib and stem. The average incubation period is 8.6±0.24 day with 84.21 percent hatching and maximum hatching of eggs observed during morning hours. Planthopper completes its post embryonic development in 42.09 days (male) and 44.4 days (female) and passes through five nymphal instars to become an adult with 89 percent larval survival and 89±0.05 percent moth emergence. Total nymphal durations are 13.8-15.4 days at

21-33°C and 50.8-52.1 days at 14-23°C. Adult male is short lived for 14.4 days as compared to female (15.9 days) with 1.0: 0.78 sex ratio. There can be eight successive generations of *S. furcifera,* the shortest generation (30 days) occurs in August at 23.9-32.8°C, whereas the longest one (78 days) occurs in December-February at 12.8-22°C [16].

The planthoppers, especially adults, prefer to stay at the upper portion of rice stems. Both adults and nymphs suck sap primarily at the base of the rice plants, which leads to yellowing of the leaves, reduced vigor and stunting of plants. Because seedlings are attacked in the nursery, infestation is often carried through eggs into the transplanted crop. Severely attacked seedlings do not grow; are stunted, wilt and eventually die. If the infestation is at the panicle initiation stage, the number of grains and the panicle length decrease. But, when attacked later during the maturation period, grains do not fill fully and ripening is delayed. When the hoppers are present in large numbers late in the crop growth stage, they are seen infesting the flag leaves and panicles. Gravid females cause additional damage by making oviposition punctures in leaf sheaths. Feeding points and wounds caused by egg-laying may later become potential sites for the invasion of bacteria and fungi. Moreover, the honeydew produced by the hopper serves as a medium for mold growth. The rice plants affected by white-backed planthopper appear uniformly in large areas throughout field rather than localized hopper burned patches as in damage by the brown planthopper. This may be due to difference in distribution patterns of the two planthopper species [17, 18].

Experiments conducted to compare plant response of japonica and indica rice cultivars to *N. lugens* and *S. furcifera* feeding, and quantify the amount of feeding by these hopper species show that reduction in plant height caused by *S. furcifera* feeding is greater than that of *N. lugens*. The effects of *N. lugens* feeding on roots are greater than those of *S. furcifera*. These results suggest a difference in the mechanism of damage caused by *S. furcifera* and *N. lugens* even though both hoppers are phloem feeders. Regardless of rice type, the reactions of different cultivars to *S. furcifera* and *N. lugens* feeding indicates that *S. furcifera* are smaller and excrete less honeydew than *N. lugens*, but their effects on tillers, leaf area and plant weight are similar to those of *N. lugens* suggesting that *S. furcifera* feeding effects at vegetative stage is greater than those of *N. lugens*. The demand for nitrogen is probably greater for *S. furcifera* than *N. lugens*, because the former contains greater nitrogen and thrives on the upper portion of the rice plant; however, this needs further investigation. The phototactic responses of planthoppers *S. furcifera* and *N. lugens* to different wavelengths, four colors of light traps (blue, green, yellow and red light-emitting diodes) placed in the same rice field along with a traditional black light trap reveal that *S. furcifera* and *N. lugens* are more attracted to blue and green lights than that of yellow and red lights. Furthermore, compared with the black light trap, the blue trap can catch more rice planthoppers and catches of other species (moths and beetles) are substantially reduced in blue light traps. Higher rainfall and lower temperature increased light trap catches of *S. furcifera*, however, wind speed is the main factor affecting the catches of *N. lugens* and the lower incidence of catches is found in the night when wind speed exceeded 3.08 m/ s. The *S. furcifera* may be flying against wind at light wind nights by 0.3-1.5 m/ s, whereas *N. lugens* may be flying down at strong wind nights by 1.5-3.08 m/ s. Consequently, light wavelengths, precipitation, average temperature and wind should be considered when monitoring of rice planthoppers by light traps, and the blue light traps are worth using for detecting [19, 20].

2.2. Brown Planthopper *Nilaparvata lugens* Stal (Hemiptera: Delphacidae)

Adults of brown planthopper *N. lugens* occur in macropterous (long-winged) and brachypterous (short-winged) forms. The macropterous form is about 3.5-4.5 mm in length. The body is brown, and the wings are transparent, with very conspicuous veins. There are many factors, which have been suggested to be responsible for wing morphism in the brown planthopper such as crowding during the development and reduction in the quality and quantity of food, short day length and low temperature. Young nymphs are white, but they gradually become darker in older instars. Adults are ochraceous brown in colour dorsally and deep brown ventrally. Females are larger (5 to 6 mm) than the males (4 to 5 mm). Eggs are 0.99 × 0.20 mm, crescent-shaped and constricted towards the egg caps. One end of the egg is united near the egg caps, while the other remains free. Macropterous females migrate into rice fields shortly after transplanting by laying groups of 5-15 eggs into the sheaths or midribs of leaves. The first instar nymphs hatch after 5-9 days and they molt five times during a period of 2-3 weeks. Initially, most of them develop into brachypterous adults, but as population density increases, or if food becomes scarce, the proportion developing into the macropterous form increases. During their adult lifespan of 10-30 days, each macropterous female produces about 100 eggs, while brachypterous female 300 to more than 700. In the tropics, *N. lugens* is active all year round and produces 3-6 generations per crop. It is not able to overwinter in temperate regions, so it migrates into these areas in the spring, often after traveling long distances. Copulation takes place just after the emergence and female starts laying eggs from very next day that hatch in about 8-10 days [21, 22].

All stages of paddy are attacked by this pest wherein both nymphs and adults penetrate the tissues of their rice host plants with their piercing-sucking mouthparts in order to ingest phloem sap. Losses of nutrients and obstruction of vessels cause yellowing of leaves. Later, the plants wilt, gradually drying up and eventually dying off. An increasing population density of planthoppers eventually leads to so-called hopperburn wherein groups of dead plants are appearing as brown and often lodge in rice field, and these patches continue to grow as insect spreads. Less severe infestations can still result in reduced plant vigor, smaller panicles, fewer ripened grains and lower grain weight. In addition to direct damage it causes, *N. lugens* is a vector of the virus diseases e.g., glassy stunt, ragged stunt and wilted stunt. All stages of *N. lugens* excrete honeydew, thus promoting growth of sooty mold. The insect prefers to feed on leaf blades and leaf sheaths at the base of plants, where it is shaded and humidity is high. Damage is generally greater in wet season than in dry season [21].

For cultural control, draining out of water from the infested field is quite effective measure in controlling of this pest and use of resistant varieties can also minimize the pest infection. Predators are the most important natural enemies of the brown planthopper. Ducks preying on rice pests in rice fields is practiced in few countries and ducks are herded into rice fields to control brown planthopper. Together with parasitoids and insect pathogens they keep down populations of this pest. An important group of predators commonly found in rice fields is spiders, but of particular importance are the hunting spiders, especially *Lycosa pseudoannulata*. It is often found near the water level, where the brown planthopper feeds. A lycosid is known to feed on as many as 20 planthoppers per day, so, its voracious appetite makes it a very important natural enemy. However, like other spiders, *Lycosa* and *Oxyopes* do not depend entirely on planthoppers for food, but there are many flies in the field, which provide the bulk of the food for spiders. During the dry season, rice field spiders are known to hide in crevices or in grasses around the field. Like all predators, spiders are very susceptible to insecticides; hence, sprays or granular applications into the water may destroy these beneficial arthropods, allowing brown planthoppers to multiply in large numbers. Spray of carbaryl, fenthion and quinalphos should be made as soon as yellow patches are seen in the field [23].

2.3. Small Brown Planthopper *Laodelphax striatellus* (Hemiptera: Delphacidae)

The small brown planthopper (*Laodelphax striatellus* Fallen) is an important rice pest that not only damages rice plants by sap-sucking, but also acts as a vector that transmits rice stripe virus, which can cause even more serious yield loss. This species exhibits mixed voltinism from 4 to 7 generations per year. Between 18 and 32℃, and 18 and 28℃, its egg duration and the nymphal duration gradually decline with increasing temperature, respectively. The planthopper overwinters as 1-5 instar nymphs. This information provides the basic data for the prediction of *L. striatellus* occurrence, and the effective prevention and control of this pest [24]. The small brown planthopper is a serious sap-sucking pest of rice wherein leaves infested by hopper turn yellow, become wilted and even die, resulting in yield loss and quality reduction. Furthermore, the hopper also transmits rice viral diseases such as rice stripe virus and rice black-streaked dwarf virus, which often cause major additional yield losses apart from just the damage by insect itself. To understand the mechanisms of rice resistance to small brown planthopper, defence response genes and related defense enzymes are examined in resistant and susceptible rice varieties in response to infestation. Results indicate that the salicylic acid signaling pathway is activated in resistant rice variety in response to hopper infestation and gene phenylalanine ammonia-lyase plays a considerable role in resistance [25].

Host-plant resistance is the most practical and economical approach to control the rice planthoppers. However, up to date, few rice germplasm accessions that are resistant to the all three kinds of planthoppers; brown planthopper *N. lugens*, small brown planthopper *L. striatellus* and whitebacked planthopper *S. furcifera* have been identified; consequently, the genetic basis for host-plant for broad spectrum resistance to rice planthoppers in a single variety has been seldom studied. However, one wild species, *Oryza officinalis*, is detected showing resistance to the all three kinds of planthoppers. The resistance gene (s) is (are) introduced into cultivated rice via asymmetric somatic hybridization. The allelic/ non-allelic relationship and relative map positions of the three kinds of planthopper resistance genes in *O. officinalis* show that resistance genes are governed by multiple genes, but not by any major gene. The data on the genetics of host-plant broad spectrum resistance to planthoppers in a single accession suggest that the most ideally practical and economical approach for rice breeders is to screen the sources of broad spectrum resistance to planthoppers, but not to employ broad spectrum resistance gene for the management of planthoppers. Pyramiding these genes in a variety can be an effective way for the management of planthoppers [26].

2.4. Leafhopper *Cofana spectra* (Distant) (Hemiptera: Cicadellidae)

It occurs in all rice fields but is most common in rain fed rice at the end of the rainy season and is minor pest. The body is yellowish, the forewings are grey white with prominent veins and the head bears four black spots. The numbers of eggs laid per female on an average are about 50. Eggs are laid in rows of 10 to 15 across the slit made by the saw-like ovipositor at the base of the plant above the paddy water. The mean incubation period, nymphal duration and survival range from 11.5 to 11.7, 21.8 to 24.4 days and 61.8 to 76.4 percent, respectively, on the two test varieties. The number of nymphs hatched on susceptibility variety is significantly more than that on tolerant. The longevity of males and females range from 23.2 to 24.8 and 26.2 to 29.1 days, respectively, on the two varieties, while the respective male to female ratios are 1: 1.1 and 1: 1.4. The fecundity/ fertility on these varieties range from 86.1 to 96.8 nymphs, while the pre-oviposition and post-oviposition periods ranged from 4.9 to 5.3, 20.3 to 21.4 and 3.1 to 3.5 days, respectively [27].

It is the largest pest among the species of leafhoppers and planthoppers. Adults rest on the lower surface of the leaves or at the base of the plant. Both nymphs and adults are xylem feeders and suck sap from leaves. The paddy plants experience damage as a result of sap sucking and oviposition by *C. spectra* followed by secondary fungal and bacterial infection on the affected part. Feeding by a large number of nymphs and adults may, however, cause typical sap loss. Leaf tips first dry up and later the leaf turns orange and curls. The pest causes stunting and yellowing of plants, and severe infestations cause plant death. The *C. spectra* are also a vector of pathogenic virus like rice yellow mottle virus. These are highly attracted to lights at night that is an ecofriendly strategy of pest control. The *C. spectra* has been tested against 7 colors for their attractively. Species showed maximum preference to yellow color followed by orange, green, red, indigo and the green. The natural enemies attacking *C. spectra* on artificially infested rice plants on the field are studied. The most abundant species of egg parasites is *Gonatocerus cingulatus* Perkins, which destroys up to 17% of the eggs. A further 6% of the eggs are destroyed by *Anagrus flaveolus* Waterh., *A. optabilis* (Perkins) and *Paracentrobia* spp. For the control of *C. spec*tra on rice, the best results are obtained with a granular formulation of carbofuran applied 30 and 60 days after transplanting to give 1.25 kg carbofuran/ ha [28].

2.5. Green Paddy Leafhopper *Nephotettix virescens* (Distant) (Hemiptera: Cicadellidae)

There are two species of green paddy leafhoppers, *Nephotettix nigropictus* and *N. virescens*. Female of *N. nigropictus* is green and a black tinge on pronotum absent. The male on the other hand has two black spots extending up to the black distal portion on the forewings unlike to *N. virescens,* where the blackspots on forewings do not extend up to the black distal portion. The *N. nigropictus* also has a black tinge along the anterior margin of pronotum and a submarginal black band on the crown of the head, which is absent in *N. virescens*. Both nymphs and adults suck the plant sap and cause browning of leaves. Both the species are known to be vectors of virus diseases of rice such as rice transitory yellowing and rice yellow dwarf. Among the two species, *N. virescens* causes more damage and it is more active during July to September. The female inserts the eggs in rows under the epidermis of leaf sheath and may lay upto 40-50 eggs. The life-cycle occupies about 25 days, the egg and nymphal periods being 6-7 and 18 days, respectively. These insects are found distributed in all rice growing areas in Asia and Africa, and populations of *N. virescens* and *N. nigropictus* are dominant in tropics [29].

It has also been known as *Nephotettix bipunctata* (Fabricius), *Nephotettix impicticeps* Ishihara, *Nephotettix oryzii* Mahmood and Aziz, and *Phrynomorphus olivascens.* The leafhopper is an important rice pest and an efficient vector of virus diseases. This species can be distinguished from other species of *Nephotettix* by the completely unmarked vertex. Females are uniformly green and males are smaller, and have black markings similar to other species of this genus. The adult insects are small and green in color, and males are characterized by two black spots on the wings. Head, pronotum and scutellum are usually green, but some males have black markings adjacent to ocelli. Forewing are with distinct spot that does not touch claval suture, but this spot may be absent or only partially represented. Apical third of tegmen is black in males; but, females have unmarked head, pronotum and clavus. The female insect lies about 25-35 eggs in the tissues of rice leaves that hatch in about 7 days. Nymphs are pale-green/ yellow with small spines on dorsal surface of abdominal segments, having small, dark-brown or black markings on dorsal surface. The nymphs undergo five successive molts between periods of 15-22 days. The insect completes its life cycle in about 20-25 days depending upon ecological conditions and the life span of adult insect is about 30 days. Warm and humid conditions are quite conducive for propagation of this pest. The leafhopper goes through several generations per rice season and life cycle lasts only 4-5 weeks. Nymphs and adults of planthoppers under favourable conditions multiply very fast [30].

Both nymphs and adults feed by extracting of plant sap with their needle-shaped mouthparts on the dorsal surface of the leaf blades rather than the ventral surface. They prefer to feed on the lateral leaves rather than the leaf sheaths and the middle leaves. They also prefer rice plants that have been fertilized with large amount of nitrogen. Rice fields infested by leafhopper can have tungro, yellow dwarf, yellow-orange leaf, and transitory yellowing diseases. Symptoms include stunted plants and reduced vigor, reduced number of productive tillers and withering or complete plant drying.

Tungro infected crops may sometimes be confused with nitrogen deficiency or iron toxicity or acid soils. To confirm cause of problem, check for virus infected plants in the fields, and the presence of the insect, for instance, white or pale yellow eggs inside leaf sheaths or midribs, yellow or pale green nymphs with or without black markings and pale green adults with or without black markings feeding on upper parts of the crop. For managing of leafhopper, use insect-resistant and tungro-resistant varieties and intercrop upland rice with soybean to reduce the incidence of leafhoppers on rice. Reduce the number of rice crops to two per year and synchronized crop establishment across farms reduces leafhoppers and other insect vectors. Transplant older seedlings (> 3 weeks) to reduce viral disease susceptibility transmitted by leafhoppers. Transplant the seedlings early within a given planting period, particularly in the dry season to reduce the risk of insect-vector and disease. Avoid planting during the peak of leafhopper activity (as shown by historical records) to avoid infestation, or light traps can be used to show pest numbers. Apply nitrogen as needed to avoid in contributing to population outbreaks by applying too much nitrogen or hindering plant recovery from planthopper damage by applying insufficient nitrogen. Control weeds in the field and on the bunds to remove the preferred grassy hosts of leafhopper and promote crop vigor. Perform crop rotation with a non-rice crop during the dry season to decrease alternate hosts for diseases [31].

2.6. Leafhopper *Pyrilla perpusilla* Walker (Hemiptera: Lophopidae)

Adults are white immediately after molting, but gradually turn straw colored, with pale green eyes, and snout-like head with black spot positioned posteriorly. The forewings are semi-opaque, yellow-brown and sparsely covered with minute black spots. Wingspan varies from 16-18 mm for males and 19-21 mm for females. Females bear bundles of cretaceous threads-the anal pads on the terminal segment. Both the adults and nymphs are very active and jump from leaf to leaf on slight disturbance. Newly emerged adult females are ready to mate in 2 days after emergence from the 5^{th} nymphal instar. Female *P. perpusilla* has a preoviposition period of 12-15 days and the average fecundity is 400-500 eggs. Eggs are white and oval, laid in clusters on both the lower and upper surfaces of leaves preferably on lower surface, covered with white waxy filaments and incubation period is 10-15 days. The first instar nymph is greenish-white with dark red eyes and two joint antennae on the head and has 2 anal filaments, while fifth instar nymph is pale to dark brown with watery green eyes. There are five nymphal instars and nymphal period is 35-50 days [32]. The adults and nymphs suck the sap from the undersurface of leaves near midrib, resulting in yellowing and in case of severe infestation; the leaves gradually turn pale and dry up. Sooty mold development and blackening of leaves due to secretion of honeydew affect photosynthesis. The leafhopper *P. perpusilla* causes direct and indirect losses to crop. The *P. perpusilla* is actually a pest of sugarcane, but occasionally it also infests paddy crop. Adults are relatively inactive during the early morning, evening and night, typically remaining on the under surface of leaves. Between around 10.00 am and 3.00 pm, they become more active and can be found on both upper and lower leaf surfaces, and jump between plants [33].

Currently, an integrated control mechanism of *P. perpusilla* combines and integrates biological (natural predators & parasites) and chemical control and employs the use of economic threshold to determine when chemical control should be utilized to prevent pests from reaching the economic injury level. The IPM is an effective and environmentally sensitive approach to pest management. The *P. perpusilla* is being attacked by twelve species of natural enemies in Pakistan, and it is reported that 80% of its egg/ population is killed by egg parasitoids, and remaining 20% by complex of nymphal and adult parasitoids and predators. Egg parasitoid *Parachrysocharis javensis* Crawford (Hymenoptera: Eulophidae) and nymphal-adult ectoparasitoid, *Epiricania melanoleuca* (Fletcher) (Lepidoptera: Epipyropidae) are observed. The *E. melanoleuca* cocoon can be used in field @ 1-5/ leaf at *Pyrilla* population level ranging from 20 to 150 nymphs + adults/ leaf, and the insecticides should not be sprayed at all. Various control methods, like, cultural, biological (release of cocoons of *Epiricania melanoleuca* @ 2500/ ha), chemical (carbofuron @ 35 kg/ ha), are applied singly and in their possible combinations with the objective to keep the pest population below the economic threshold level and to find the most economical and effective method of control, for communication to the farmers. Application of cultural + chemical + biological controls in combination, results in a minimum population of *P. perpusilla* [34].

3. Integrated Pest Management in paddy

Integrated Pest Management (IPM) is an eco - friendly approach for managing of pest and disease problems utilizing all possible available methods and techniques of pest control such as cultural, mechanical, biological and chemical methods in as compatible and scientific manner as possible to suppress pest population below economic injury level. Over use of insecticides is the main cause of outbreaks of hoppers. When insecticides are used, predators and parasites are killed, and hopper populations resurge i.e., the numbers after spraying are higher than before; this is because there are no natural enemies. Integrated pest management programs stress the need to maintain biological control of natural enemies, and also include tolerant varieties. The routine use of broad-spectrum insecticides should always be avoided. Integrated pest control more precisely, involves use of a wide range of skills and practices to control pests including the need based use of pesticides. There have been developed an IPM and communication strategies using a heuristics approach to motivate farmers to reduce their early-season spraying. This campaign has reduced farmers' insecticide use and lowered vulnerability to outbreaks on rice farms. Farmers need IPM training that can focus on conserving of natural biological control and reducing pesticide use for thousands of farmers. These efforts may seem to keep hopper pests below damaging levels in most by explore of new approaches to develop sustainable management strategies [35, 36, 37]. The following paragraphs highlight recommended management options for major rice hopper pest:-

3.1. Detection and Inspection of Hopper

Rice growers should look at the base of the plants for the nymphs, and winged and wingless adults, where it is shady and humidity is high. Look for the sooty mold fungi that often accompany large numbers of the insects. More than 3-5 insects per tiller are considered high invasion, needing more intensive observation and possibly insecticide treatment. The basic way of determining economic action thresholds can be described in a simple formula: AT = C PDK

where, AT = action threshold, C = cost of control measure, P = price of crop (per unit, e.g., hectare), D = loss in yield without control (tons per hectare), K = reduction in damage due to control measure, Preconditions for applying of any method to determine a threshold value in a scientific way are close monitoring of incidence of the respective pest and ability in operating formulae and models involved in calculating threshold limits. About 4 weeks after transplanting, or whenever nymphs first appear, begin sampling for hoppers. For transplanted rice, randomly select 10-20 plants by crossing the field diagonally in each block, note which hopper species are present (on stems, leaves and water surface), count eggs, nymphs and adults, and record observations on a monitoring form. On the basis of these data, periodic forecasting information reports, outbreak alarm and warning reports can be issued if necessary. Treatment thresholds vary according to hopper generation and species, however, use the general guidelines stated below to help in determining treatment needs. For older rice plants, grasp the plant, bend it over slightly, and gently tap it near the base to see if hoppers fall onto the water surface. There is no need to scout for hoppers beyond the milk stage and at a density of 1 hopper/ stem or less; there is still time to act in case of the numbers increase [38].

i. Green leaf hopper: 2 insects per hill in tungro endemic areas, 10 insects per hill in other areas at tillering stage and 20 insects per hill at mid tillering to panicle initiation to booting stages.

ii. Brown planthopper: 5 to 10 insects per hill at tillering stage, at panicle initiation to booting stage 20 insects per hill, while 5-10 insects at flowering stage and after flowering.

iii. White backed planthopper: 10 insects per hill at tillering stage and 5-10 insects per hill at flowering stages, and after flowering. Use light traps (an electric bulb or kerosene lamp near a light colored wall or over a pan of water) at night when rice is prone to hoppers attack and do not place lights near seedbeds or fields. If the light trap is inundated with hundreds of hoppers, it is a signal to check the seedbed or field immediately.

3.2. Biological Control Practices

There are a number of natural predators of the planthopper, spiders eat the nymphs and adults, as do coccinellid beetles, dragonflies, damselflies and are mirid egg-sucking bugs. There are two species of egg-sucking bugs, *Tytthus chinensis* (Stal) and *Cyrtorhinus. lividipennis* Reuter (Hemiptera: Miridae, and there are likely to be wasp parasitoids that attack eggs, as well as fungal pathogens and mites. Biological agents such as spider, water bug, frog, mirid bug, damsel fly, dragon fly, grasshopper, Coccinellids, Bracon, wasp, Trichogramma, Telenomus etc., should be conserved. Root dip treatment of rice seedling with Chlorpyriphos is safe for natural enemies. The major pathogens found inflicting hoppers is *Pandora delphacis*, and its suitability as a fungal insecticide formulation is more virulent, predominant and more adaptable to the rice eco-system. Eggs of leafhoppers and planthoppers are parasitized by *Oligosita* spp., *Paracentrobia* spp., *Anagrus* spp., *Gonatocerus* spp., and Camptoptera spp. Apply split applications (three times) of nitrogen fertilizer, and allow plants (weeds) on the bunds (and at the borders of dryland crops), and between fields, to flower in order to attract natural enemies [39; 40].

Predacious arthropods, including spiders, attack all stages of rice insects and these are abundant in rice fields. The wolf spider, *Lycosa pseudoannulata* is probably the most important predator in rice fields in Asia. The diet of the wolf spider depends on the types of insects that are available, but leafhoppers and planthoppers are the major prey. Lycosa feeds on both hopper nymphs and adults and is considered to be a major regulator of brown planthopper populations. One wolf spider can eat up to 45 hoppers per day. Pathogens belonging to the fungi, bacteria and virus groups attack rice insect pests and play an important role in the regulation in rice insect pest populations. Among the entomogenous fungi, *Metarhizium anisopliae*, the green muscardine fungus, is a common insect pathogen. Fungus *M. anisopliae* commonly attacks rice planthoppers, leafhoppers, rice black bugs and Scotinophara spp., [41, 42].

3.3. Cultural Practices

Cultural practices include selection of healthy seeds, resistance or tolerance variety, raising of healthy nursery, early and timely sowing or planting, seedling root dip or nursery treatment in hopper endemic area, destruction of left over nursery, normal spacing, balance use of fertilizer, proper water management (alternate wetting and drying to avoid water stagnation in plant hopper endemic area, and harvesting close to ground. Cultural practices such as maintaining of weed-free fields should be observed to minimize insects' infestation and synchronized planting over a large area allows the most susceptible stage of rice to escape from damage. Simultaneous rice cropping, if practiced over a wide area and rotated with secondary crops, would break the life cycle of the insect pest. Immediate destruction of rice stubbles and ratoons of a harvested rice crop would help to keep down the population of the pest. Plant spacing should allow some sunlight to reach the basal portion of the plant. The crop planted by the end of July suffers little from leafhoppers and planthoppers, but crop planted later is severely attacked. Gradual buildup of the hopper population from the beginning of the rice season could cause severe damage to late-planted rice. Weedy fields increase the hopper population, and near rice crop maturity the planthoppers tend to be more abundant in weedy than in weeded fields, probably because the dense vegetation of weedy fields provides an environment suitable for the insect multiplication [43].

3.4. Mechanical Practices

Some key mechanical practices are clipping off rice seedling tips before transplanting, removal and destruction of disease or pest infested plant parts, use of rope in rice crop for dislodging immature stages, and collection and destruction of egg mass and larvae. Sanitation aims to remove all breeding or hibernating sites and sources of food of the insect. Excess water also hinders development of hoppers, raising the water level can destroy eggs laid in the leaf sheaths and drives the insect from its favored location on the lower stems. Close spacing of rice plants is believed to contribute to the rapid increase of the hopper population. Close planting, particularly when associated with repeated foliar sprays of parathion enhances the development of the hoppers. That may be because of foliar sprays may not reach insects that are protected by the thick canopy of the rice crop, but they destroy natural enemies inhabiting the foliage. Solar and ultraviolet radiation act abiotically against the hopper and restrain its increase. Spacing that allows some sunshine to reach the basal area of the rice plants for some part of the day may thus be another reason for smaller insect populations. Females reared on plants receiving high nitrogen levels show increased fecundity due to contribute to the thickness of the canopy. High rates of nitrogenous fertilizers may result in more protein and amino acid synthesis by the rice plant. The proteins and amino acids are among the essential requirements for growth and development of immature insects and are often needed by adults for the reproductive process [44, 45].

3.5. Chemical Control

Chemical pesticides are to be applied on need base, and judiciously and recommended chemicals are to be applied at right time at recommended dose. Insecticides should only be used when planthopper populations are likely to reach an economic injury level; otherwise natural enemies may be destroyed and planthopper populations can return greater than before. Only apply an insecticide to the seedbed for hoppers if all of these conditions are met; an average of more than one planthopper per stem, on average more planthoppers than natural enemies and flooding of the seedbed is not an option. The systemic insecticide, Orthene (acephate), has been used for many years against the brown hoppers. Check for latest recommendations from government agriculture extension personnel, as well as the timing and method of application. Avoid indiscriminate insecticide use, which destroys natural enemies [46, 47].

3.6. Insect Resistant Cultivars as a Component in IPM Systems

Breeding for insect resistance has only been a focus of rice development programs since the long times. As a result, rice breeding programs throughout the world have developed and released commercial varieties with resistance to numerous insect species. The most widely grown rice varieties have multiple resistances to several diseases and insects, including the brown planthopper, good grain quality and high yield potential. Before planting, choose varieties that have tolerance to the planthopper. Avoid staggered planting by preventing of planthoppers moving from older to younger crops in ever greater numbers. Plant at the same time as neighbor farmers, within a period of 2-3 weeks and remove volunteer plants. Rotate rice with other crops and do not plant rice crops one after another, so that large populations of the planthoppers can migrate easily between them. During growth, drain the paddies for 3-4 days during the early stage of infestation. After harvest, do not keep tthe ratoon crop i.e., allow it to re-sprout and continue growing after harvesting. Plough the field after harvest and remove stubble that would otherwise allow the brown planthoppers to feed on plant [48].

Insect resistant varieties are being successfully utilized, as a major component in rice IPM program. The IPM programs utilize biological controls, traditional cultural controls, insecticides and pest resistant varieties to varying degrees. When new varieties with multiple resistances are introduced there are only minor fluctuations in yield, as these varieties have greater yield stability. Sequential release of varieties with diverse genes is necessary to cope with the development of new races and biotypes of diseases and insects, respectively. The cornerstone of the rice IPM strategy is the use of multiple pest resistant varieties in a mix with natural biological control and other control tactics [49]. Examples of how insect resistant varieties can be integrated with biological, cultural and chemical control are presented below:-

3.6.1. Plant Resistance to Insects and Biological Control

Insect resistant varieties may have an adverse effect on natural enemies by reducing of prey density, but they are generally considered to be compatible with biocontrol agents. Pest resistant varieties can shift the pest: predator ratio in favor of biological control. In field studies, brown planthopper: spider ratio decreases with an increase in the level of resistance. Host plant resistance enhances predatory activity in a manner, which may be synergistic. Predation rate of the wolf spider increases when the spider preys on brown planthopper adults on resistant cultivars. The mechanism involved is believed to be the restless nature, and subsequent frequent movement of the brown planthoppers on the resistant variety, which exposes them to a greater degree to detection by the spider. Combinations of host plant resistance and predation by the mirid bug *C. lividipennis* have a cumulative effect on the population increase of the green leafhopper *N. virescens*, which is a vector of the dreaded tungro virus [50].

3.6.2. Plant Resistance to Insects and Cultural Control

Most cultural practices are considered to integrate well with other control tactics in IPM systems, and the use of resistant varieties, combined with good cultural management, is considered to be a powerful tool in managing of pests. Examples of integration are resistant varieties plus fertilizer management and pest evasion techniques. Increased amounts of nitrogen fertilizer have been one of the major components contributing to the high yields of modern crop cultivars. However, high plant nitrogen levels are generally favorable to pest insect populations. Results of a study indicate that nitrogen fertilizer favours brown planthopper population growth, regardless of the level of resistance in the host plant, but the population increase is least at the higher levels of resistance. Cultural practices employed to evade pest attack include early maturing varieties, which are harvested before the pest reaches at level of damaging populations. Brown planthopper: predator ratios on early maturing rice varieties are lower than those on late maturing varieties. Incorporation of even moderate levels of brown planthopper resistance into early maturing varieties enhances the level of protection against this pest [51, 52].

3.6.3. Plant Resistance to Insects and Chemical Control

Because of the weakened physiological condition of insects feeding on resistant varieties, control of the surviving insects with insecticides is more effective, when pests are on resistant, than when they are on susceptible, varieties. Brown planthopper mortality, when reared on either a moderately resistant, or a highly resistant rice variety, is higher than when feeding on a susceptible variety. Another interaction of host plant resistance and insecticides is the relationship between level of resistance and insecticide-induced brown planthopper resurgence. Brown planthopper populations on a resistant rice variety treated with a resurgence-inducing insecticide only reached 10 insects per plant, whereas the population on a treated susceptible variety is 1,100 per plant. Thus, when insects other than the brown planthopper reach populations above the economic threshold and require insecticide treatment, the level of brown planthopper resurgence can be reduced, by planting a brown planthopper resistant variety [53, 54].

3.6.4. Development of Biotypes on Insect Resistant Rice Varieties

Insect populations have a wide range of genetic variability that maximizes their fitness in the presence of genetic diversity of host plants. The widespread planting of one rice variety (monocrop) has significantly decreased the genetic diversity of rice plants. As a result, some rice insect species have overcome the resistance of certain rice varieties. Such apparently new forms of pests have been termed as biotypes which refer to a population of insects that is capable of damaging plant varieties that are resistant to other populations of the same species. Brown planthopper biotypes have been a very severe problem and to cope with the brown planthopper biotype problem, several gene deployment strategies have been proposed to increase the stability of insect resistant varieties. These strategies are sequential release where a variety with a single major resistance (R) gene replaces a variety with an R gene that has been overcome by the selection for a virulent biotype, gene pyramiding, the incorporation of two or more major R genes into the same variety to provide resistance to two or more biotypes, horizontal resistance- a type of resistance that is expressed equally against all biotypes, gene rotation that is a strategy where varieties with different R genes are used in different cropping seasons to minimize selection pressure on given resistance genes, and geographical deployment that is the planting of varieties with different R genes in adjacent cropping areas [55, 56].

3.7. Use of Biotechnology

The recent advances in biotechnology can provide the possibility of solving some of the constraints that have limited the practical use of genetic resistance to insects in pest management programs. Biotechnology provides new possibilities of manipulating insects resistant rice germplasm. Wide hybridization is a plant breeding tool for the incorporation of alien genetic variation from wild species of *Oryza* into commercially useful cultivars. Wild rice species are a rich source of R genes for use in breeding programs for insect resistance. The breeding program has utilized the wild rice species *O. brachyantha* in the development of crosses with *O. sativa* in the development of hoppers resistance and some progeny are resistant to all known biotypes of the hoppers. Genetic transformation scientists are incorporating novel genes for resistance into rice through transformation. Genes, such as the *Bacillus thuringiensis* gene coding for toxic proteins, inhibitors of digestive enzymes such as protease inhibitors, and ribosome inactivating genes are being transferred to rice [57].

Wolbachia that are maternally inherited intracellular alpha-proteobacteria have been used by both microinjection and nested Polymerase chain reaction (PCR) to show that the Wolbachia naturally infecting *Drosophila simulans* Sturtevant can be transferred into a naturally Wolbachia-infected strain of the small brown planthopper *L. striatellus*, with up to 30% superinfection frequency in the F (12) generation. The superinfected males of *L. striatellus* show unidirectional cytoplasmic incompatibility when mated with the original single-infected females, while superinfected females are compatible with superinfected or single-infected males. This study implies a novel way to generate insect lines capable of driving desired genes into Wolbachia-infected populations to start population replacement [58].

4. Conclusion

Many species of insects attack rice crop, which can be divided into two major categories including borers and sucking pests of both groups that can damage the crop severely resulting into low yield and inferior quality grain. Nymphs and adults of plant and leaf hoppers remove the contents of leaf cells, leaving behind empty cells that appear as pale yellow spots or stippling. If populations are high, the entire leaf may be pale yellow or white. Symptoms depend on rice variety, number of hoppers and plant age, All these affect the number of tillers and panicles that develop, plant height, the amount of unfilled grains and injury from feeding and egg laying, which allows entry by fungi and bacteria, as well as blackening of stems by sooty molds. The severe infestations by large numbers of hoppers cause plants in the milk or dough stages to gradually turn yellow from the tip, brown, dry out and collapse, which is a wilt, known as hopperburn. The most susceptible time is from tillering to flowering and hopper burn is more common in paddy than dryland rice. The insects make more feeding marks and excrete less honeydew on resistant varieties than on the susceptible. The numbers of feeding marks increase with the increase in the plant age of varieties, while the honeydew excretion is decreased. Within the IPM principle, economic decision-making remains at the core of rice protection, but the approach also incorporates good farming practices and active pest control within a production context. The IPM in rice seeks to optimize production and maximize profits through its various practices. More importantly, the clear consensus is that pesticide use in rice can be significantly reduced (without loss of yield or profit) by training of farmers in practical ecology and consequently moving away from the standard prophylactic calendar based spraying. Integrating the use of fertilizer and resistant varieties with other control methods can achieve both high rice production and hoppers control. There must be close cooperation among researchers, extension folks and local authorities to guide and supervise the IPM program in rice.

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