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A Global Perspective of Rice Brown Planthopper Management Ⅱ- After Green Revolution Era

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Abstract Rice Brown Plant hopper, *Nilaparvata lugens* (Stal) (BPH) has started becoming a major pest in tropical rice growing countries only after major areas were covered by dwarf varieties or high yielding varieties (HYVs). Detailed discussion both historical and experimental evidence on several possible causes like Changed architecture of rice plant, Associated change in agricultural practices, change in micro-climate in rice crop ecosystem, Lack of insect resistance in dwarf varieties, Increased use of insecticides, Consequent destruction of natural enemies, Development of insecticide resistance is presented. Among these, microclimatic factors in rice ecosystem, notably optimum temperature, low wind movement, high water vapor pressure and consequent high relative humidity among abiotic factors and nitrogen rich plant sap among biotic factors appeared to be the most important. Lack of BPH resistance in HYVs does not appear to be the primary cause. Higher insecticide usage in HYVs appeared to be responsible for persistence of BPH menace partially due to destruction of natural enemies and more importantly through development of insecticide resistance and resurgence. However this seems to be secondary cause for BPH problem in all tropical rice growing countries of Asia including China and India.

Keywords Rice; Brown plant hopper; *Nilaparvata lugens*; Biotypes; Long range migration; Insecticide resistance

INTRODUCTION

Rice Brown Plant hopper, *Nilaparvata lugens* (Stal) (BPH) is an ancient insect associated with rice ecosystem in all tropical rice growing areas in Asia. However it is a well-recognized fact that BPH has started becoming a major pest and later even as a threat to rice production in these countries only after major areas were covered by dwarf varieties or high yielding varieties (HYVs). The initial period of such flare up slightly differed among the tropical countries depending on the accessibility of HYVs to the local farmers. That is probably the reason why the first international symposium on BPH held at International Rice Research Institute (IRRI) in 1978 was titled as "Brown Plant Hopper: Threat to Rice Production in Asia". In The Philippines, major BPH damage was observed in 1973, although there was gradual rise from 1969 onwards. This might be due to proactive approach of IRRI in extension activities in the country along with research at that time. In fact the first country that tasted green revolution in rice was the Philippines as seed of IR8 "the wonder rice", which was termed at that time, was made available to farmers by IRRI itself from 1969. In India, the most severe outbreak of BPH was reported from Kerala state at the end of 1973 and early in 1974. But author's own experience shows that it has started its demonic form in kharif 1973 in Krishna-Godavari delta of A.P. on Jaya variety and probably in other major rice growing deltas of the country. In Indonesia, Sri Lanka, Thailand and Solomon Islands BPH damaged rice in a significant way in 1974, from 1975 in Malaysia and Vietnam, from 1976 in Bangladesh. Interestingly no recorded evidence was available from China at that time (Dyck and Thomas, 1979).

CAUSES OF BPH OUT-BREAKS IN TROPICAL RICE GROWING COUNTRIES AFTER GREEN REVOLUTION ERA:

If one examines the possible causes of sudden demonic emergence of BPH after 1972 and increased and persistent devastation it causes every year, many points could emerge.

1. Historical evidence from temperate and tropical countries

2. Changed architecture of rice plant
3. Associated changed agricultural practices
4. Possible change in micro-climate in rice crop ecosystem
5. Lack of insect resistance in dwarf varieties
6. Increased use of insecticides
7. Consequent destruction of natural enemies
8. Development of insecticide resistance and resurgence

Let us now examine each of those possible reasons.

1. HISTORICAL EVIDENCE

JAPAN: The BPH has evidently been a pest of rice in Japan since ancient times. Outbreaks date back to AD 697 or 701. Since then there have been numerous records of out-breaks, many covering large areas, and some causing severe famine. BPH outbreaks occurred in 1897, 1912, 1926, 1929, 1935, 1940, 1944, 1948, 1960, 1966, and 1969.

KOREA: In ancient Korean records, 36 out of 167 references to insect infestations can possibly be attributed to plant hoppers. Hopper damage was reported as early as 18 AD. In 20th century BPH outbreaks occurred in 1912, 1921, 1922, 1923, 1965, 1966, 1967, 1969, and 1970. BPH outbreak was most severe in 1975 in the southwestern part of Korea (Dyck and Tomas, 1979).

Thus in both these temperate countries BPH was very serious since long time. A critical analysis of the above historical record clearly indicates that BPH was very serious from the beginning of 20th century in temperate rice growing regions of Japan and Korea while in most of the tropical countries it became serious only after the large scale cultivation of dwarf varieties/hybrids in these countries, since 1973.

Single crop of rice is grown in Japan and Korea since ancient times and japonica varieties were under cultivation there. While in all these tropical countries tall indices which are photosensitive were grown with purely organic manures.

At present we know very clearly that BPH has to undertake long range migration from mainland China to reach Japan and Korea and has a time frame of just 3-4 months to multiply and cause damage. In all tropical countries, BPH was present in rice ecosystem since ancient times. The insect had the chance to multiply year round because two crops of rice are possible. Yet it could never rise to the status of a major pest. This very clearly points that japonica varieties and the associated agronomic practices must have had major impact on favorable development and multiplication of BPH which were lacking in tall indicas, but become available in short statured dwarf indica varieties or hybrids.

DEVELOPMENTS IN JAPAN FOR INTENSIVE RICE PRODUCTION

Towards the end of 19th century Japanese government decided to make the country self-sufficient in rice, their major food crop. They have appointed a high power committee. As per its recommendation, they started implementing a form of "systematized rice farming technique" which combined modern biology and local farmers' experience. This was termed as Meinji Agronomy with five most important points: 1. breeding of varieties which were adoptable to fertilizer, short culm and much tillering. 2. Split application of fertilizers i.e. Introduction of top dressing. 3. Thorough weeding. 4. Thorough control of insects and disease 5.Water-depth control management at every stage of crop growth. Because of such intensive farming practices based on heavy fertilizer application, yield per hectare doubled in 30 years i.e. 1.5 tons in 1878 to 3 tons in 1910. From about 1930, rice productivity in North-Eastern Japan increased rapidly and the yield per hectare has become higher than in the South-West. This was due to increasingly larger fertilizer dose. By 1930Japan was already one of the most heavily fertilized countries in the world with nearly 100 kilograms of nitrogen input per hectare." (Natsukikanazawa, 1993). Almost a similar varieties and agronomic practices were followed in Korea also. This historical evidence very strongly proves the point that changed micro-climate in high yielding varieties in all tropical countries due to changed architecture as well as associated agronomic practices was the prime cause of BPH epidemics after 1973. The ecological conditions during HYV era are very similar to those existing in Japan and Korea almost from end of 19th

century and beginning of 20th century. Thus micro-environment including microclimate and food quality is prime cause of BPH outbreaks.

INSECTICIDE USE IS NOT ORIGIN OR PRIMARY CAUSE OF BPH OUTBREAKS BUT AN INEVITABLE CONSEQUENCE

The benefits of DDT, the first synthetic insecticide were demonstrated in the 1940s when it was used in World War II (1939-1945) to clear out mosquito-infested areas prior to invasion. Even after the war, the use of DDT in the United States almost completely wiped out malaria and yellow fever. In tropical areas, the use of DDT has helped save millions of lives that would otherwise have been lost to disease. DDT was also routinely applied as a crop dust or water spray on orchards, gardens, fields, and forests. At one point it was registered for use on 334 agricultural crops. Endrin is an organo-chlorine insecticide which has been used since the 1950s against a wide range of agricultural pests, mostly on cotton and also on rice, sugar-cane, maize, and other crops. Ethyl parathion was first registered as a pesticide in the U.S. in 1948.

BPH was such a menacing problem in Japan for such a long period before 1940 when no synthetic pesticide was ever available to man, and had never been used on rice or any crop for that matter. Therefore, insecticide use appears to be not the primary cause or origin of BPH out breaks in tropical countries. The whole tragedy of over dependence on insecticide use as sole management tactic, their excessive and abuse and consequent development of insecticide resistance and resurgence, all seems to be more a consequence rather than a primary cause of present day BPH out breaks in all rice growing countries of Asia.

2. CHANGED ARCHITECTURE OF RICE PLANT

Before 1960, tall indica varieties with low productivity (2.0- 2.5 tons/ha), photosensitive, usually long duration (150 days or more) were grown in all tropical Asia. Fertilizer use was almost not known to rice farmers. Organic matter from cows and buffalos, sheep etc. was source of plant nutrition. It is short statured, high-tillering, non-lodging, stiff culmed, photo-insensitive, high fertilizer responsive rice varieties with high potential for grain yield was the hall mark of rice revolution in tropical Asia. Most significant among such varieties is the IR8 released for large scale cultivation in 1967-68 by International Rice Research Institute (IRRI), The Philippines, followed by “Jaya” during 1969, by All India Co-Ordinated Rice Improvement Project (AICRIP), Hyderabad, India, later named as Directorate of Rice Research (DRR). Both these varieties were popular during early stages of rice revolution in tropical Asia almost up to late seventies and early eighties. Both these varieties were highly susceptible to BPH and WBPH. These two varieties also served as a major breeding source material for later high yielding dwarf varieties in several countries. Majority of those evolved varieties were also susceptible to BPH and also for WBPH. It is at this juncture when substantial tropical rice areas were covered by dwarf varieties, BPH has started appearing in epidemic form revealing its real potential as a threat for rice cultivation. These simple chronological events reveal that changed plant architecture has certainly something to do with BPH outbreaks.

3. ASSOCIATED CHANGES IN AGRICULTURAL PRACTICES

Before the introduction of HYVs application of NPK in the form of fertilizers to rice was very low or almost negligible in all tropical rice growing countries including China and India. But with the realization among farmers that the real potential of high yielding varieties can be realized under high fertilization, farmers started applying higher NPK. This trend continuously increased with time. It is also noteworthy that farmers tended to apply usually more than recommended nitrogen although this tendency towards P and K is very limited. Main reason is that P and K increase the general health of rice crop and yield potential of the crop while nitrogen makes rice crop look greener immediately after application. This creates the impression in farmers’ mind that his crop is set to yield more although the real contribution of the greenness to yield enhancement is not always up to expectation. High N application tended to make rice crop succulent and attracts more infestation by insect pests and incidence of diseases. BPH infestation is generally higher in rice fields with high N application

compared to neighboring rice fields with recommended N. There are many publications in India and other rice growing countries that high N leads to higher BPH build-up. The reasons could be multifarious, attracting more BPH from neighboring fields, enhancing rapid build-up of the pest through high fecundity, faster growth, and enhanced longevity and so on. But the important point is that generally enhanced N application associated with changed agronomic management practices of HYVs could be one of the causes of rapid and persistent build-up of BPH in all tropical rice growing countries after 1973.

Another important observation of most rice entomologists is that even with in the same field, where ever higher nitrogenous fertilizer (usually urea) has fallen during broad-casting, rice crop grows more luxuriantly with darker green color in those spots in the field. These are usually the spots where BPH starts building up faster. That is the reason why extension workers are advised to check such spots for the presence of BPH first. The absence of BPH in such spots is almost a clear indication that the pest is not present in that field at significant levels. This generalization is indisputable although the magnitude of its contribution may vary with area and other associated management practices.

4. POSSIBLE CHANGE IN MICRO-CLIMATE IN RICE CROP ECOSYSTEM:

There appears to be a change in some of the critical abiotic factors in micro-environment of crop canopy in rice ecosystem. Let us analyze such possible differences in dwarf varieties compared to earlier tall indicas with regard to different abiotic factors (Krishnaiah, 2014 c).

IMPORTANT DIFFERENCES IN CROP CANOPY OF TALL INDICAS VS DWARF HIGH YIELDING VARIETIES (HYVs)

In tall indicas crop canopy is loose at the base of the plant at the time of planting. Crop canopy will continue to be loose throughout the crop growth from base of the rice plant near water surface up to the top. This naturally allows better air movement and light penetration through the entire crop canopy from planting till harvest.

On the other hand, in HYVs there is loose system immediately after planting. But with increase in crop growth, a relatively closed type of system starts developing at the base of rice plant. Thick plant population and faster and high tillering ability of dwarf varieties/hybrids naturally helps in development of a closed type of system. The tightness and height of the closed system will be confined only up to 10 cm for 35-40 days after transplanting. This slowly increases up to 30 cm and above when crop reaches panicle initiation stage. This progressive development in closeness and tightness of crop canopy at base of rice plant where BPH is mainly confined can have major implications with regard to BPH multiplication. Let us examine the effect of this major difference in crop canopy on different abiotic factors like temperature, relative humidity, water vapor pressure , wind movement and light intensity on biology of BPH either directly or indirectly.

TEMPERATURE

Temperature as a component of microclimate in rice ecosystem in rice canopy can have two types of effects on biological parameters of BPH. 1. It can influence the selection of micro habitat within the rice crop canopy. 2. Temperature can have profound direct influence on various parameters like duration of development of different stages, wing form ratio and reproductive rate etc. Studies by Isichaikul and Ichikawa (1993) under controlled conditions showed that selection of microhabitat in the rice crop canopy by BPH nymphs was not influenced by temperature in the range of 20℃ to 35℃. Studies by Krishnaiah et al (2005) under controlled environmental chamber conditions and green house conditions revealed that temperatures ranging from 25 to 30℃ and 70 to 90% RH are favorable for multiplication of BPH. The insect cannot tolerate > 35℃ of constant temperature and >47℃ of variable temperature during 24 hours period. BPH cannot survive and multiply at 10℃ or below under tropical conditions.

Detailed data on temperature variations in rice field at different crop canopy levels particularly near water surface in HYVs and traditional varieties are not available in literature. However, when rice crop is subjected to higher temperature during day time, the

entire system up to the bottom of crop canopy becomes hot. When there is cool environment during night, it is more likely that temperature in lower crop canopy may be a little bit higher in dwarf varieties compared to tall indicas because of tightness of the canopy system. Thus it is more likely that diurnal and nocturnal temperatures near water surface are less variable in HYVs compared to tall varieties.

RELATIVE HUMIDITY AND WATER VAPOR PRESSURE

Studies on optimum relative humidity for BPH conducted with environmental chambers showed that 70-90% RH is optimum with regard to all critical biological functions and stages. (Krishnaiah et al., 2005). Isichaikuland Ichikawa (1993) studied the effect of environmental factors determining the selection of the microhabitat by BPH in the crop canopy under laboratory conditions. Nymphs were released to a potted rice plant covered with a transparent acrylic cylinder. When the top of the cylinder was kept open (open condition), the temperatures in the cylinder were almost constant, and relative humidity in the cylinder decreased with the increase of the height from the water surface of the pot. In the open condition, most nymphs and all exuviae were found on the basal parts of rice plants where the humidity was more than ca. 90% R.H. When the top of the cylinder was kept closed with para-film (closed condition), the temperatures in the cylinder were almost constant, and relative humidity in the cylinder was more than 95% R.H. throughout the height of crop canopy. In the closed condition, the nymphs and the exuviae were distributed sparsely all over the vertical system of crop canopy or on all parts of rice plants from base of the stem to leaf tips. Field studies by Win et al (2011) showed that BPH population was high at 64 and 74 days after transplanting associated with heavy rainfall, high temperature and high humidity. But there are no field studies available in literature on the quantitative variations in RH at different crop canopy levels in tall indicas and HYVs.

Nowhere, in the entire BPH literature on the ecological conditions, the influence of water vapor pressure has been indicated as the possible cause of BPH build up in HYVs compared to traditional tall varieties.

Let us first understand, what is vapor pressure?

The pressure exerted by a vapor on the solid or liquid phase with which it is in equilibrium. At pressures lower than the vapor pressure, more atoms or molecules of the liquid or solid vaporize and escape from the surface of the liquid or solid than are absorbed from the vapor, resulting in evaporation. At the vapor pressure the exchange is equal and there is no net evaporation. Also called evaporation pressure (INTERNET 1)

As the temperature of liquid or solid increases its vapor pressure also increases. Conversely, vapor pressure decreases as the temperature decreases. Vapor pressure is measured in the standard units of pressure. The International System of Units (SI) recognizes pressure as a derived unit with the dimension of force per area and designates the Pascal (Pa) as its standard unit. One Pascal is one newton per square meter ($N \bullet m^{-2}$ or $kg \bullet m^{-1} \bullet s^{-2}$).

Relative humidity is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The relative humidity of air depends on temperature and the pressure of the system of interest. The relative humidity of an air-water mixture is defined as the ratio of the partial pressure of water vapor (H_2O) in the mixture to the saturated vapor pressure of water at a given temperature.

Relative humidity is normally expressed as a percentage and is calculated by using the following equation: [1]

phi = {{e_w} \over {{e^*}_w}} \times 100\%.

What Is the Relationship between Air Pressure and Humidity or water vapor pressure?

Air has many different kinds of molecules; nitrogen, oxygen, argon and water vapor etc. Nitrogen molecules are heavier (have greater volume) than oxygen molecules and oxygen molecules are heavier than water vapor molecules.

Nitrogen and oxygen molecules collide with other molecules forcefully, whereas the lighter water vapor's collisions are less powerful. The water vapor molecules

do not travel far after a collision, so they collide more frequently.

Therefore, as humidity increases (more water vapor in the air), air pressure decreases, and as humidity decreases, air pressure increases.

Air temperature plays a part of this dynamic as well. The higher temperature normally results in higher air pressure. At higher temperature the air can hold more water vapor which means higher relative humidity when there is external water supply or water layer below the air. But when the air is present in a tightly closed system, without any external water availability, relative humidity decreases. Thus there is need to understand all these points before analyzing rice ecosystem with regard to relative humidity and water vapor pressure (INTERNET 2.-7).

VAPOR PRESSURE OF WATER IN A RICE FIELD IN TALL INDICAS VS HYVS OR DWARF VARIETIES

As already discussed, in tall indicas where the crop canopy is loose, there is very little scope for increase in water vapor pressure at the base of rice plant. At the most it will be for 1-2 mm above water surface or slightly higher. Similar condition is likely to continue throughout the crop growth as the crop canopy continues to be loose even up to harvest. On the other hand in HYVs, there is loose system in crop canopy immediately after planting. But with increase in crop growth, a relatively closed type of crop canopy starts developing at the base of rice plant. The tightness and height of the closed system will be confined only up to 10 cm for 35-40 days after transplanting. This slowly increases up to 30 cm and above when crop reaches panicle initiation stage. This progressive development in closeness and tightness of crop canopy at base of rice plant where BPH is mainly confined, simultaneously allows increased water vapor pressure. The vertical plane or vertical zone of increased water vapor pressure is governed by the presence of water layer above soil surface and the quality of the crop canopy in terms of closeness and tightness. Thus both the presence of water in a rice field and thickness of crop canopy are closely related to BPH population dynamics in a rice field throughout the crop growth.

Another point is that lower variations in diurnal and nocturnal temperature at the base of the plant in HYVs can improve water vapor pressure at base of the rice plant and could aggravate the problem of BPH multiplication.

LIKELY IMPORTANCE OF WATER VAPOR PRESSURE ON LIFE SYSTEM OF BPH

At high water vapor pressure, the insect can easily maintain its water content in the body for a longer time at very low energy consumption for this biological function. Unnecessary feeding on xylem just to maintain its water condition in the body can be drastically reduced. These two can save nutrients and energy in the insect system which can be easily utilized for enhancing maximum potential towards its realization in reproduction.

WIND MOVEMENT: Precise data on wind movement near the water surface in rice fields planted with dwarf varieties and the traditional tall indicas are not available in literature. Generally wind movement is lower in a closed type of system in crop canopy and therefore increases relative humidity and water vapor pressure in rice crop canopy in the ecosystem.

LIGHT INTENSITY: Narayanasamy (1975) reported that the population density of BPH was higher at a "lower sunshine period." Excessive solar radiation is said to prevent population increase of BPH in rice ecosystem (Pathak 1968: Anon. 1975). However, not much information is available in literature on the influence of light intensity on biology and multiplication of BPH in a rice ecosystem. Rice entomologists know BPH as a photo tactic insect and can be collected at light traps. But this is only a behavioral aspect. This does not refer to influence of light intensity on biological parameters and consequent multiplication of the insect (Dyck et al., 1979). Isichaikul, and Ichikawa (1993) in their studies already described, observed that in both open and closed conditions, the patterns of nymphal distributions on rice plants during the dark regime were the same as those during the light regime under 25±2 ℃ and 16L:8D. This indicates that light intensity is not critical for vertical distribution of BPH in rice crop canopy.

RELATIONSHIPS AMONG RELATIVE HUMIDITY, WATER VAPOR PRESSURE, WIND MOVEMENT AND LIGHT INTENSITY

From the above discussion, it is clear that in dwarf indicas or HYVs, having closed or tight system in crop canopy can have higher RH and also higher water vapor pressure, lower wind movement and lower light penetration in lower portion of rice crop canopy compared to tall indicas. All these are likely to have impact on biology and multiplication of BPH.

PRACTICAL OBSERVATIONS AVAILABLE AS ON TODAY TO SUPPORT THIS HYPOTHESIS

1. It is a common observation under farmers' fields that BPH build-up is generally high in the interior of a rice field and certainly the build-up does not start from an edge of the rice field near the bunds.
2. Within a given field, BPH multiplies faster in thick crop canopy spots or areas as visualized by relatively higher population levels in such spots irrespective of other factors.
3. When a population of 5 insects / hill is artificially released in newly transplanted rice crop, actual build-up of the insect starts from 35-40 days after transplanting when there is sufficient crop growth and canopy development.
4. A number of studies on the influence of hill spacing while planting indicated higher population and build-up of BPH in closely planted crop (10 x 10 cm) compared to normal spacing of 20 x 15 cm. Population was still lower when the spacing was increased to 25 x 25 cm or 30 x 30 cm, keeping all other agronomic practices the same.
5. Leaving alley-ways of 30cm width for every 4-5 meters of rice crop planting is the recommended practice to lower the build- up of BPH. Usually, BPH is not seen near edges of alley-ways and if present only in the central area of each 4-5 meter strip of planted area.
6. When the water is removed from rice field, BPH multiplication gets slowed down. It is in fact a recommendation to drain out water immediately, in BPH epidemic situations before actual insecticide application is initiated.
7. Under laboratory conditions, at 40℃ BPH dies very fast when kept away from rice plants. Under the same temperature conditions, BPH can survive for quite long time when kept in enclosed chambers under water saturated conditions even without food. BPH can survive and even multiply at the same temperature when allowed to feed on plants.
8. It has been observed at DRR and also at IRRI that when a rice field with screening material for BPH is surrounded with a plastic sheet up to a height of 90cm or more, there was faster build-up of BPH than the fields without such a sheet. Same is the case when a square meter or more area in a rice field is enclosed with a plastic sheet up to 90cm height or higher than the areas without such a cover. Apart from prevention of escape of BPH from such enclosed areas and prevention of natural enemies from outside, comparatively higher water vapor pressure coupled with higher relative humidity also appear to have their contribution towards faster build-up of BPH under these conditions.
9. All the above observations strongly suggest that lower wind movement, resulting in higher relative humidity and high water vapor pressure favor BPH build-up in modern dwarf high yielding varieties compared to earlier tall indicas. This could be the major factor along with nutritious food for BPH to become a menace in entire tropical rice growing areas of India and other Asian countries.

Future research can quantify these important ecological factors responsible for BPH multiplication and build-up in a rice ecosystem. These are only conceptual at the movement of time.

5. LACK OF INSECT RESISTANCE IN DWARF VARIETIES

It is generally argued that modern HYVs are not having resistance to BPH and that is the major factor contributing for BPH build-up. It is to some extent true. Among the HYVs or the hybrids which are occupying major chunk of rice area doesn't possess good level of resistance with antibiosis as the contributing factor. Even if there are claims of having BPH resistance in some varieties it is not of sufficient level to contain BPH populations. But the important point here is how far there was BPH resistance in those tall indicas which were under cultivation before green revolution era. Of nearly fifty thousand rice germplasm comprising mostly tall indicas which were evaluated for BPH

resistance in several countries only 200-300 could be identified as having moderate to good level of resistance to the insect. Even at IRRI, out of 44,335 germplasm accessions screened for BPH biotype 1, only15.4% of them were resistant while for BPH biotype 2 and 3, 1.9% and 1.8% of the screened germplasm exhibited resistant reaction.(Brar et al., 2009).This very fact is the testimony that host-plant resistance(HPR) in those varieties popularly grown before green revolution era was not the factor responsible for keeping BPH under check for thousands of years in the entire tropical Asia including China.

6. INCREASED INSECTICIDE USE

It is an accepted fact that apart from BPH other insect problems like, leaf folder, hispa, gundhi-bug and panicle mite have also started appearing in more areas with greater intensity during HYV era compared to traditional tall varieties. The reasons for this could be many but the fact remains that insecticide use on rice has tremendously increased after HYV cultivation. The target pests could be BPH alone or leaf folder and stem borer or a combination of these pests. During the initial phases of BPH epidemics broad spectrum insecticides like monocrotophos, phsphamidon, carbary, acephate, carbofuran, phorateetc were recommended and used by farmers. This has contributed for increased dosage/ha of insecticides during early stages of green revolution. But after 2000 more pest specific or more precisely, pest group specific insecticides have come under use. Neonicotinoids like imidacloprid, thiamethoxam and chitin inhibitors like buprofezin were the main arsenal used against BPH and WBPH. At the same time cartap hydrochloride, indoxacarb and flubendiamide became popular against stem borer and leaf folder.

Much controversy has arisen regarding synthetic pyrethroids in rice as several studies in India and other tropical rice growing countries have convincingly proved that almost all synthetic pyrethroids tested in rice ecosystem have resurgence causing effect on BPH to a lower or higher degree. Thus a consensus has emerged among rice entomologists that no synthetic pyrethroid should be recommended in rice ecosystem irrespective of their moderate efficacy against leaf folder. This idea was first resolved by DRR and later followed by almost all agricultural universities in India. In other tropical rice growing countries also almost the same consensus has emerged. With strict compliance of this among all stake holders like farmers, insecticide companies, extension workers, insecticide induced resurgence of BPH will not be a limiting factor in successful management of the pest in future.

Another important point here is when rice crop with HYVs is grown under normal recommended agronomic practices in BPH endemic areas in India without any insecticide application from sowing to harvest, then, also there is build-up of BPH to a level capable of causing hopper-burn at least in some parts of the field. This has been observed for four consecutive seasons at Rice Research Station, Maruteru, West Godavari Dist. A.P. which is a well-known BPH endemic location during 2002-2003.(Krishnaiah et al 2002, 2006a& 2007). Several such instances have been noticed in delta areas in India. Some reports from other rice growing Asian countries also confirm this fact. Thus it is clear that use of insecticides in rice crop is not the primary cause for BPH build-up from 1973 onwards rather an inevitable consequence that forces the rice farmers just to protect their crop from imminent danger of hopper-burn if left unattended.

7. CONSEQUENT DESTRUCTION OF NATURAL ENEMIES:

Among the natural enemies of BPH, green mirid bug *Cyrtorhinus lividipennis*, black mirid bug *Tytthus parviceps*, and a number of species of predatory spiders are important. Nymphal parasite cum predators like *Gonatopus* spp. and other related species, and a few species of egg parasitoids have also been reported to feed on BPH. Mirid bugs feed on eggs and early stage nymphs, but their populations often follow the population development of BPH and cannot effectively check the pest build-up. Spiders are very non-specific predators which feed on all animal fauna in rice ecosystem and consume BPH just as small proportion of their total diet. Thus they cannot be depended upon as a natural biological control phenomenon to check BPH build-up. The very fact that BPH can build-up to a stage of causing hopper-burn in an insecticide free rice crop of HYVs is a testimony that natural biological control alone cannot be depended upon for BPH management under any circumstances.

All the information on various natural enemies of BPH has been published after it became destructive during HYV era and very little information is available during earlier period. However it is logical to presume that almost same qualitative composition of BPH natural enemies existed during tall indica period also.

After 1973, increased insecticide application in rice ecosystem might have lowered population of natural enemies during crop growth although precise qualitative changes in composition of natural enemy complex are not documented. Potential contribution of natural enemy complex of BPH to check the pest outbreaks is low. It is more likely that qualitative and quantitative changes in natural enemy complex due to changed plant architecture or the insecticide use is not the primary cause for destructive appearance of BPH after 1973.

8. DEVELOPMENT OF INSECTICIDE RESISTANCE IN BPH AFTER LARGE SCALE EPIDEMICS

With the discovery of insecticidal property of DDT in 1939 and later inventions of organophosphates and carbamates, all these were extensively used against BPH in Japan and Korea resulting in some times serious cases of insecticide resistance against these compounds. Later on, whatever the progress in technological advancements in insecticide field, the prime target pest was BPH. The groups like, ether derivatives, neonicotinoids, chitin inhibitors, phenyl pyrazoles and the most recent ryanodine receptor blockers which were evaluated and used against BPH were all the achievements of Japanese pesticide industry. In fact almost all insecticides used against BPH in India, China and other rice growing tropical Asian countries had their origin in Japan.

As these insecticides were also used in China and as a result, there was steady development of insecticide resistance in BPH in immigrating population to Japan. This was well correlated with insecticide use pattern. Even with in the same rice crop season, there were several instances of steady increase in insecticide resistance in BPH in Japan.

In India insecticide resistance in BPH has not been studied until 1996. (Sarupa et al., 1998). Even in her studies also there was no detectable resistance in BPH against traditional insecticides like monocrotophos, phosphamidon, carbaryl etc. Neo-nicotinoid group insecticides imidacloprid, thiamethoxam etc. were used on large scale from 2000 onwards. Within 3-4 years high levels of resistance against imidacloprid was recorded in BPH populations from west Godavari, A.P. (Krishnaiah et al., 2006b; Jhansi Lakshmi et al., 2010). At present also there are no concerted efforts even to monitor the level of insecticide resistance in BPH in India about which there is hue and cry in China and other rice growing countries. Thus the real magnitude of insecticide resistance problem in BPH in India is not exposed to the public eye.

CONCLUSIONS

1. Critical analysis of various studies on BPH and historical evidence clearly points that micro-environment both biotic and abiotic prevalent in dwarf varieties and absent in previous tall indicas are the primary causes of persistent BPH out-breaks in all tropical rice growing countries to day.
2. Insecticide use appears to be an inevitable consequence and is a secondary cause for BPH out breaks mainly through insecticide resistance development insect resurgence and also due to natural enemy destruction.
3. Studies on fundamental and applied aspects of insecticide resistance development in BPH and also in WBPH are required for systematic and planned usage of these chemicals in future. Research on safer chemicals both for humans and environment has to be pursued at greater vigor and strength.
4. Fundamental studies on quantification of water requirement of BPH can also deepen our understanding about its physiology and may bring dramatic turn in its very management strategy.

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