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Review Article

Open Access

## A Global Perspective of Rice Brown Planthopper Management III - Strategies for BPH Management

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**Abstract** Rice Brown Plant hopper, *Nilaparvata lugens* (Stal) (BPH) management strategy at present involves traditional approaches like, Using Resistant Varieties, Cultural Management and Use of Insecticides. Natural Biological Control is considered only in delaying insecticide application at favorable times and Use of Bio-Agents is non-existent. Varietal resistance could not achieve desired results due to inefficient and inadequate screening and breeding techniques presently employed to transfer highly complex multi-gene multi QTL based trait. This can possibly be improved by following traditional approach of screening and selecting plants directly under field conditions. Leaving alley-ways, optimum nitrogen application, optimum plant population are largely followed in many countries. New possibilities by changing the rice planting design can be experimented and exploited. Insecticide use is the major tactic followed in almost all the countries with inevitable consequences of natural enemy destruction and more importantly insecticide resistance development and pest resurgence. The scope of utilizing natural enemies as a major tactic appeared to be remote. Alien sources like lectins or Similar chemicals which can directly affect BPH, Alien organisms or the chemicals that disrupt the physiological base of Galbanchina, Alien genes which can produce compounds related to insect molting hormones or juvenile hormones, in rice plants are the distant goals but worthy of initiation. After quantitative assessment of water vapor pressure and humidity on BPH, Chemicals interfering with water balance in BPH and even suitable dusts to mechanically disrupt insect body wall seem to have scope in future.

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

### Introduction

Rice Brown Plant hopper, *Nilaparvata lugens* (Stal) (BPH) is a non-traditional insect pest that has risen from the most in-significant state to the most important level even threatening the rice production. Today it is considered as the number one yield limiting factor in all rice growing countries both in tropics and temperate regions. Whatever very little evidence we have today and very little imagination we could extend, strongly suggest that “niche” of BPH in dwarf varieties has reached its most optimum level due to change in micro-ecological factors, both biotic and abiotic. Lot of research efforts need to be put to understand and quantify the basic ecological factors that are responsible for survival, multiplication and perpetuation of the insect throughout the rice growing world. Extraordinary ability of BPH in long range migration clearly reveals that it is an invasive species.

This makes our job still more complicated. Therefore developing basic knowledge about the pest should be an integral part of our whole BPH management strategy.

So far, traditional approaches like 1) Using Resistant Varieties 2) Natural Biological Control and Use of Bio-Agents 3) Cultural Management 4) Use of Insecticides were largely utilized. But these did not give sufficient solace to the crying rice farmer so far. Hence Non-Traditional Approaches need to be given more importance in future along with improving the performance of traditional approaches.

### HOST-PLANT RESISTANCE

After 1970, when BPH has started becoming a major menace in all tropical rice growing countries, attempts were made to identify the sources of resistance to the pest. Simultaneously rice scientists tried to incorporate

resistance in agronomically capable varieties at IRRI and many other countries including India. But, even after 44 years there are no resistant varieties evolved which could withstand the pest attack under farmers' conditions. If at all some varieties were released they could not stand for more than one or two years. Finally varietal resistance could not play a role in minimizing insecticide application. Let us analyze to understand the possible reasons.

#### **IDENTIFICATION OF RESISTANT DONORS:**

Since 1970 more than fifty thousand germplasm have been screened at IRRI for resistance to BPH and 15.4% , 1.9% and 1.8% of them were found resistant to biotypes 1, 2, 3 respectively (Brar et al., 2009). From 1973 mass screening of germplasm has been initiated at Directorate Of Rice Research, Hyderabad, India (Kalode and Khrishna, 1979). More than 300 Cultivars showing high level of resistance to BPH in greenhouse tests were identified. IR26 was resistant to BPH in the Philippines and several other countries was susceptible in India, and in Sri Lanka. A number of varieties like ARC 6650, ARC 7080, ARC 10550, ARC 14636, etc. Which exhibited high level of resistance to BPH in India showed clear susceptibility for the 3 biotypes at I.R.R.I. (Kalode and Khrishna, 1979). Thus the concept of natural existence of biotypes was visualized.

In spite of tremendous efforts by rice breeders all over India only few instances of BPH resistant varieties could become practical. IET 6314 and IET 6315 were first varieties from DRR. IET 6315 had good level of resistance but did not have good yield potential. So it could not find acceptance with farmers. IET 6314 was good yielder and released in Tamil Nadu as CO-42. But it succumbed to BPH attack with in the same season of release under farmers conditions. Later IET 7575 was released. But it was not accepted by farmers because of difficulty in grain thresh-ability. Almost similar situation occurred in Philippines and other tropical rice growing countries including the tropical China.

#### **BASIC ASPECTS OF RICE VARIETAL RESISTANCE TO BPH**

International symposium on plant hoppers conducted at IRRI during 2009 reveals detailed account on BPH varietal resistance.

Twenty one genes conferring resistance to BPH were so far identified in rice. In addition a number of QTLs present in various rice chromosomes were also identified for different biotypes in various countries (Brar et al., 2009).

A brief account of complexity of interactions between the insect and the host plant can be described as follows:

#### **EFFECTS ON BPH BEHAVIOR:**

- Reduced feeding
- Increased probing
- Decreased probing time
- Increased ingestion of xylem
- Reduced ingestion of phloem
- Reduced contact time between insect mouth parts and plant surface
- Increased salivation time

#### **EFFECTS ON BPH FITNESS PARAMETERS**

- Reduced uric acid content
- Lower weight gain
- Reduced crude fat content
- Reduced lipid synthesis
- Lower weight and lipid advantage in macropterous females
- Lower glycogen reserves
- Lower soluble (and overall) sugar content
- Lower fat content
- Reduced ingestion and assimilation of food
- Reduced nymphal survival—decreased adult emergence
- Reduced adult survival (longevity)
- Increased movement and activity
- Decreased settling on plants
- Increased development time
- Reduced proportion of brachypterous adults
- Lower potential flight duration of macropterous females
- Increased susceptibility to predators
- Increased parasitism
- Increased potential for predation (hopper-predator ratios)
- Reduced number of females with swollen abdomens
- Reduced fecundity (number of fully developed eggs on dissection)
- Reduced egg-batch size
- Reduced egg hatchability or reduced egg survival
- Reduced ovariole length
- Reduced proportion of adult females copulated
- Reduced oviposition
- Reduced egg-laying on plants

Table 1 Genes for brown planthopper resistance in rice and their reaction to different biotypes across the globe.

Gene	Variety	author	Reaction to biotype		
			South-Asian	East -Asian	South-East-Asian
BPH1	Mudgo		S	S	S
BPH2	ASD7		S	R/S	R/S
BPH3	RathuHeenati		R	R	R
BPH4	Babawee	Kawaguchi et al (2001)	R	R	R
BPH5	ARC 10550	Khush et al (1985)	R	S	S
BPH6	Swarnalata	Kabir and Khush (1988)	R	S	S
BPH7	T12	Kabir and Khush (1988)	R	S	S
BPH8	Chin Saba	Nemoto et al (1989)	-	R	R
BPH9	Karahamana	Su et al (2006)	-	R	R
BPH10(t)	<i>O. australiensis</i>	Ishii et al (1994)	-	R	R
BPH11(t)	<i>O. officinalis</i>	Hirabayashi et al (1998)	-	-	-
BPH12(t)	<i>O. latifolia</i>	Yang et al (2002)	-	R	-
BPH6, BPH13	<i>O. officinalis</i>	Renganayaki et al (2002)	R	R	R
BPH14	<i>O. officinalis</i>	Yang et al (2004)	-	-	-
BPH15	<i>O. officinalis</i>	Yang et al (2004)	-	R	-
BPH15(t)	<i>O. officinalis</i>	Ren et al (2004)	-	-	-
BPH17(t)	RathuHeenati	Sun et al (2005)	-	R	-
BPH18	<i>O. australiensis</i>	Jena et al (2006)	R	R	R
BPH 19(t)	AS20-1	Chen et al (2006)	-	-	-
BPH20(t) BPH21(t)	<i>O. minuta</i>	Rahman et al (2009)	-	R	-

Note: R = resistant, S = susceptible. - = information not available. (Modified from Brar et al., 2009).

## **FINAL EFFECT ON PLANTS: REDUCED KILLING OF PLANTS** (modified from Horgan, 2009).

Detailed account of host plant Resistance-breaking ability and feeding behavior of BPH has been given by Seo et al (2009).

What we have to learn from these facts and what can be our future course of action?

The above facts clearly points that so far we are attempting to incorporate the highly complex multi-gene and multi QTL controlled BPH resistance through inefficient and inadequate screening and breeding techniques. The following are some suggestions for improvement.

## **UTILIZATION OF EXISTING DONORS FOR EVOLVING BETTER RESISTANT VARIETIES TO BPH.**

Among 300 to 400 donors already identified about 10 best donors can be put to large scale test under field conditions. Those can be grown each in about half an acre to one acre fields by staggered planting at 2 months interval in tropical Asian states. This enables us to maintain the presence of rice plants throughout the year. The fields can be covered with cloth mesh. Continuous release of BPH from all possible sources in neighboring areas can be made for a year. Finally 2-3 best donors which exhibit better survival for local biotypes can be selected. By following the traditional breeding methods attempts can be made to transfer the maximum possible level of resistance to already existing varieties in each of the rice growing regions of Asia. All the testing and selections need to be made under field conditions only. This alone can ensure the maximum possible harvest of BPH resistant genes and mechanisms into new varieties.

### **a) NATURAL BIOLOGICAL CONTROL AND USE OF BIO-AGENTS**

Few hundreds of species of biological agents have been recorded feeding on BPH in rice ecosystem. Most important among these are green mirid bug, black mirid bug, velid bugs, spiders, coccinellids, ground beetles, drynid predator cum parasites (*Gonatopus* etc.), fungal pathogens etc. Spiders are non-specific predators just eating BPH as a small fraction of their

diet. Fungal pathogens are mainly saprophytic and rarely effective. Populations of drynids, coccinellids and ground beetles are very low. Velids are just present on water surface and feed if any BPH happens to fall on water surface.

Green mirid bugs and black mirid bugs are relatively high in number compared to other bio agents. However, their population is very low in initial stages of crop growth. They start appearing in rice ecosystem when BPH populations are high and are near economic threshold. Even from that time also, they never surpass or even come to proximity to BPH with regard to population in a field or a part of it. Mirid bug population is high only after the field is completely damaged and substantial populations of BPH emigrate from the field. Main reason is, ecological conditions congenial for BPH are not congenial for mirid bugs and their reproductive rate is very less compared to BPH. Mirid bugs can hardly lay about 70-100 eggs/ female compared to 300-500 eggs per female in case of BPH (Krishnaiah et al., 2002, 2006, 2007). Field experience of many rice entomologists in endemic areas revealed that BPH cannot be controlled even to 10-15% level by all the natural enemies put together.

Most important drawback even for very limited scope for bio-control of BPH is that none of the parasites or predators can be mass multiplied and released as augmentative or even inoculative methods. Mass rearing techniques could not be standardized for mirid bugs in spite of attempt by several workers.

### **b) CULTURAL MANAGEMENT**

Important cultural management options are:

**1. Maintaining optimum plant population:** Usually plant population of 32-36 hills per square meter is ideal for most situations under transplanted conditions during kharif season and 40-42 hills per square meter during rabi season. However, this plant population can be increased for varieties with lesser duration. Even at this recommended and ideal plant density also BPH can occur and damage. If crop density is lowered it will adversely affect yield which is not acceptable to farmers.

## 2. Leaving alley ways of 30 cm. width for every 4 meters width of planting

This tends to inhibit multiplication of BPH and WBPH due to aeration as already discussed. This also facilitates inter-cultivation and spraying operations and human movement in the field. This has become a normal practice in all BPH endemic areas of tropical Asia and practically adoptable under single rice crop areas also. The loss of yield due to loss of planted area under alley ways is compensated by higher productivity in hills on both sides of alley ways.

## 3. Changing Rice Planting Design

Historical and experimental evidence so far available strongly suggest that in dwarf varieties or HYVs there is progressive accumulation of higher water vapor pressure and consequent higher relative humidity starting from soil surface, then in the lower crop canopy and finally in upper crop canopy with advancement in plant age after transplanting. This was not present in tall indicas prevalent before green revolution era in India and other tropical rice growing countries. This is an inevitable consequence due to their very size, high tillering ability and also due to associated high fertilizer application in dwarf varieties.

The only way to overcome this is to create a micro-climate in HYVs similar to the one existed in tall indicas. This can possibly be done by making provision for free air movement within the crop canopy right from planting time. But at the same time it should be done in a way that it will not adversely affect yield, does not add cost to farmer, should be practical, and can easily be adoptable by rice farmer. Thus by following the new planting design described below we will be removing the bottle neck of favorable microclimate for BPH in dwarf HYVs, at the same time retaining all the benefits of these wonderful dwarf varieties responsible for rice revolution.

### Method of new rice planting design:

Transplanting should be done in units of 1m x 1 m or 2m x 2m or 3m x 3m or 4m x 4m or 5m x 5m with 25 to 30 centimeter strip of unplanted area on all sides of each transplanted unit. When the whole rice field is

planted in this manner, the rice crop is present in patches of quadrats or squares with alley-ways all around. The details are below:

Planting Area	Alley-way width	Net planted area (%)
1m x 1m	30 cm	59.17
2m x 2m	30 cm	75.61
3m x 3m	30 cm	82.64
4m x 4m	30 cm	86.53
5m x 5m	30 cm	88.99
1m x 1m	25cm	64.10
2m x 2m	25cm	79.01
3m x 3m	25cm	85.20
4m x 4m	25cm	88.58
5m x 5m	25cm	90.70

This method can be compared with normal method of planting along with 30 cm alley-ways after every 4-5 meter strips of transplanted area in the same field, in two equal halves. However, Method of planting i.e. Line planting or random planting and spacing or plant population per square meter should be the same as that of the earlier half. Only difference should be the change in planting design. It will be meaningful only it is tried in a plot of an acre or slightly less but in any case should not be less than half an acre.

### How does this work?

➤ The new planting design is expected to create more unfavorable micro-climatic conditions for BPH right from planting time by creating unfavorable conditions at the time of settling and delaying the onset of multiplication process there by total time available for the insect for multiplication is reduced.

➤ This allows sufficient air movement in the entire field. So there will be very little scope for BPH multiplication on rice plants in the periphery of each square shaped planting unit. The plants in the periphery of each planting unit will have higher



number of tillers per hill and more vigorous due to their opportunity of access to nutrients from soil in alley-ways areas. Finally those plants can compensate the loss in yield due to unplanted area.

- Plants in the center of the square are with less number of tillers. So the scope of damage on those interior plants is also relatively low.
- The experience of many rice scientists suggest that yield loss will not be there when transplanted in this manner when all other agronomic conditions are the same.

#### **Expected difficulties and strategy for overcoming:**

- Good care should be taken in weed control in early stage of transplanting both by suitable herbicide application and by maintaining optimum water depth up to 30-35 days after transplanting.
- If labor availability permits, inter-cultivation in the alley-ways area can be undertaken around 20-25 days after planting. That certainly will create more favorable soil conditions for crop growth and also controls weeds.
- This is hypothetical at the movement of time but worthwhile for experimentation and adaptation.

#### **Optimum size of planting unit:**

Size of planting unit to prevent BPH multiplication can vary depending on soil fertility level, management practices, variety, Season, recommended planting density etc. In light soils as well as under lower level of management, the total proportion of planting area can be increased up to 88.99% by following 5m x 5m • planting units and 30 cm alley-ways on both sides. Similarly for medium type of management and soil fertility conditions 4m x 4m planting units and 30 cm alley-ways on both sides can be adopted with net planting area of 86.53%. In situations where high level of fertility status exists and the farmers are capable of high level of management 3m x 3 m planting units and 30 cm alley-ways on both sides can maintain a net planting area of 82.64 %. The whole philosophy is, there should not be reduction in yield per unit total area while creating unfavorable climate for BPH. The loss in output from unplanted area must be made good by higher output from the plants in the borders of planting units. In general decreasing the

width of alley-ways to 25 cm is not preferable as it improves the chances of BPH multiplication in the field, although it slightly improves the percentage of net area planted. A suitable model can be chosen and adopted in different areas after thorough evaluation.

#### **Important points in Rice Planting Design:**

- As we increase the area of planting unit, the chances of BPH multiplication improves. When the width of alley-ways is reduced it also results in enhancing BPH multiplication. If the area of planting unit is reduced the net transplanting area is lowered. This tends to lower the overall yield. So we have to strike a balance between the two after thorough evaluation in a given situation.
- Normally, this practice is expected to check BPH without any insecticide application. But, we need not always aim at completely avoiding insecticide use. We can allow a very limited use confining to the central area of each planting quadrat. Quantity of insecticide used will be very less and Easy to apply.
- Most important of all is the selection and implementation should not result in yield reduction when the total gross planted area is considered.
- This can go a long way of BPH management mainly in tropical countries and possibly in temperate rice growing areas around the Globe.

**4. Balanced fertilizer use:** Not exceeding the recommended doses of nitrogenous fertilizers and not lowering the level of phosphate and potash fertilizers from their recommended dose is the thumb rule. This is normally followed by majority of rice farmers in endemic areas in tropical Asia. Major problem is, this cannot check normal multiplication of BPH and “hopper burn” is often seen in fields with normal recommended practices. At the most balanced fertilization can only reduce the danger of very rapid multiplication if more than recommended nitrogenous fertilizers are applied. Farmers cannot afford to apply less than recommended nitrogen levels as it will certainly affect the potential yield in a given situation.

**d) USE OF INSECTICIDES:**

Table 2 Recommended Insecticides for BPH Control Along With Relevant Details (Krishnaiah et al. 2004; 2008)

Insecticide	Dosage of formulation /Acre	Group	Effective- ness duration	Remarks
Buprofezin 25% SC	350ml	Chitin inhibitor, insect growth regulator	14-20 days	Insects have to molt for increasing in size. This acts by contact only on nymphs at molting time. Inhibits egg laying by adults. There is no resistance reported to this insecticide in BPH in Asian countries till date.
Imidacloprid 200 SL	60-70ml	Neonicotinoid	12-15 days	Systemic insecticide. Resistance in pests including BPH and WBPH is wide spread for this insecticide in India and other tropical rice growing countries including China.
Thiamethoxam 25 WG	30-60g	Neonicotinoid	14-16 days	Systemic insecticide. Resistance to this insecticide is already present in BPH in India and other tropical rice growing countries including China.
Acetamiprid 20 SP	40-60 ml	Neonicotinoid	10-12 days	Systemic insecticide. Popular to a limited extent in tropical rice growing countries including China and India.
Thiacloprid 22 SC	250 ml	Neonicotinoid	10-12 days	Systemic insecticide. Popular to a limited extent in tropical rice growing countries including China and India.
Ehiprole 5SC	300-400 ml	Phenyl-pyrazole	10-12 days	Slow initial action. But has good persistence. Effective against insects with neonicotinoid resistance. Moderately popular in tropical rice growing countries including China and India.
Fipronil 5SC	300-400 ml	Phenyl-pyrazole	10-12 days	Slow initial action. But has good persistence. Effective against insects with neonicotinoid resistance. Popular to a limited extent in tropical rice growing countries including China and India.
Ethofenprox 10 EC	400ml	Ether derivative	12-14 days	Safe to natural enemies and human beings. Works through contact action. Effective against insects with neonicotinoid resistance. Popular to very limited extent in tropical rice growing countries including China and India, mainly due to high cost and poor availability.
Acephate 75 SP	500-600g	Organophosphate	7-10days	Relatively safe to natural enemies. Popular in many of the tropical rice growing countries including China and India mainly due to low cost, effectiveness against other pests like stem borer and leaf folder. Easy availability. Effective against BPH with neonicotinoid resistance.
Monocrotophos 36 WSC	400ml	Organophosphate	7 days	Toxic to humans and natural enemies. It was Popular in many of the tropical rice growing countries including China and India during 1980's and 1990's. This was mainly due to low cost, effectiveness against other pests like stem borer and leaf folder. Effective against insects with neonicotinoid resistance. But recently banned in some countries.
BPMC (fenbucarb) 50 EC	400-500 ml	Carbamate	5 days	Has ovicidal action and also systemic action. It was popular in some countries during 1980's and 1990's. After 1998 when neonicotinoids became available it's use is drastically reduced in all countries. Effective against insects with neonicotinoid resistance.
MIPC (isoprocarb) 50 WP	500g	Carbamate	10 days	Has systemic action. Effective against insects with neonicotinoid resistance. It was popular in some countries during 1980's and 1990's. After 1998 when neonicotinoids became available it's use is drastically reduced in all countries.
Carbaryl 50 WP	750 g	Carbamate	5-7 days	Contact and systemic action. Moderately effective. It was popular in some countries during 1970's and 1980's. After more effective insecticides became available it's use is drastically reduced in all countries.
Carbosulfan 25 EC	750 ml	Carbamate	10-12 days	Works through contact and systemic action. After neonicotinoids became popular it's use is drastically reduced in many countries. Still it is used in some countries. Effective against insects with neonicotinoid resistance.

## **PRECAUTIONS WHILE CHOOSING AND USING THE ABOVE INSECTICIDES:**

Determine the level of BPH population in a given field. Select at least 50 hills per acre representative of the area. Estimate the average BPH+WBPH per hill based on all the hills. If BPH and/or WBPH are 15-20/hill, if the alley ways were not left at planting time, make alleyways and drain out the water. Spray any one of the recommended insecticides depending on the duration of protection required and the residue implications. After 15 days, if the population persists, repeat the spray, but the insecticide should not be the same or from the same group. This is very essential to reduce the risk of resistance development in BPH or WBPH populations. If average mirid bugs number per hill is equal to BPH/WBPH number, delay spraying by 4-5 days.

## **5) NON-TRADITIONAL APPROACHES:**

As a long range solution, finding an alien resistance sources both for BPH and WBPH will be worthwhile.

1. It could be some other plants like the lectins already identified. But these lectins so far identified are far inferior in their effectiveness in relation to the requirement.
2. Similar chemicals could be from some bacteria or some other organisms living in soil or some other source which can directly affect these insects.
3. Alien organisms or the chemicals that disrupt the physiological base of Galbachina, the organisms present in BPH and WBPH which are now considered as vital for the survival of these plant hoppers.
4. Alien genes which can produce compounds related to insect growth regulators (compounds similar to molting hormones or juvenile hormones) in rice plants which can interfere in molting process in BPH. A variety of such compounds are already identified in a number of plants. By following the reverse genetics with the help of biotechnological techniques it is not impossible to isolate the genes responsible for production of such compounds and their incorporation into agronomically desired rice varieties. This, no doubt requires a lot of effort in fundamental research. But it is worthwhile to initiate a programme in this direction as a long term goal.
5. Research can be initiated right now to study the details on the effect of water vapor pressure and

consequent relative humidity on biology of BPH under field conditions. After establishing this and working out the details, a lot of techniques to deplete the water content of the insect body can be devised and used. These can be:

- A) Chemicals which can effectively interfere with water balance in BPH and WBPH.
- B) Even dusts with particles having surfaces that can even mechanically disrupt insect body wall.

However, all these again demand a lot more efforts in fundamental research before coming up with anything worthwhile and practical methods on any of the aspects suggested above.

## **SPECIAL STRATEGIES FOR TACKLING BPH IN INDO-GANGETIC PLAINS OF INDIA**

(Krishnaiah, 2014 a & b)

Indo-Gangetic plains of India comprise of northern states of Bihar, Jharkhand, Uttar Pradesh, Uttaranchal, Haryana, and Punjab where a single crop of rice is grown during rainy season or kharif season from May-June to October-November. South-Asian biotype has to migrate from southern or eastern states where two crops of rice are grown into these states to cause damage.

## **STUDYING BPH MIGRATION PATTERN AND IDENTIFYING SOURCE OF MIGRANTS:**

Studies on BPH populations in the areas where they are causing damage and likely sources of migrant populations over a period of time with regard to certain aspects can help to identify the source of migrants. There are five such important aspects

1. Virulence spectrum of the insect to a set of varieties with known resistance genes
2. Virulence pattern with regard to transmission of virus diseases.
3. Developmental pattern of morpho-forms.
4. Spectrum of insecticide resistance for recommended insecticides against BPH and those which are commonly used in rice ecosystem against other pests.
5. Mathematical models on weather conditions and their relation with possible BPH migratory populations.

Let us examine the scope of each of these aspects with regard to South-Asian biotype of BPH prevalent in Indian sub-continent

**1. Virulence spectrum of BPH to a set of varieties with known resistance genes:** Such varieties are usually called differentials. Differences in virulence in different populations present in different states to such differentials will normally be present after release of varieties with one or two genes and large scale adoption of those varieties in a state or states for a minimum of 4-5 years. Then population of BPH present in those areas is likely to develop virulence to overcome the resistance effect of that particular gene or genes. As the matter stands today, there are no varieties with BPH resistance that have been grown over vast areas in any rice growing state or even a tract. So this approach is unlikely to lead us to identification of source of BPH migrants to Indo-Gangetic belt states.

**2. Virulence pattern with regard to transmission of virus diseases:** Grassy stunt and ragged stunt are the two important virus diseases transmitted by BPH. As far as the whole of Indian subcontinent is concerned, BPH has never caused serious damage to rice crop as vector of grassy stunt or ragged stunt anywhere in the whole subcontinent during the past 40 year history of large scale damage by BPH. This fact certainly indicates that this aspect cannot give clues regarding the source of long distance BPH migrants to Indo-Gangetic belt states where a single rice crop is grown.

**3. Developmental pattern of morph forms:** During a long history of BPH migrants to Japan and intensive studies by entomologists there, led to identification of discernible differences in percentage of macropterous and brachypterous forms that develop in the progeny of migrants. This helped them to some extent to identify the source of migrants either from South-East Asian countries like Vietnam or from mainland China along with viral transmission pattern. However, pursuing this aspect is unlikely to lead Indian scientists to obtain the information regarding source of migrants to Indo-Gangetic belt states starting from Jharkhand to Punjab.

**4. Spectrum of insecticide resistance for recommended insecticides against BPH and those which are commonly used in rice ecosystem against other pests:** If we closely follow the pattern of insecticide use in India since 1973 against BPH and also against other important insects like stem borer, gall midge and leaf folder, we get certain clues. During the earlier years up to 1995, major insecticides used in India against BPH were monocrotophos, carbaryl, acephate, BPMC, MIPC and carbosulfan as sprays. However, there were no indications of insecticide resistance development in BPH against any of these insecticides till 1996 (Sarupa et al., 1998). After 1999, neonicotinoids like imidacloprid, thiamethoxam, acetamiprid, thiacloprid were introduced into insecticide market and used extensively against BPH in many rice growing states in India. By 2004, discernible level of resistance in BPH has been recorded in Krishna-Godavari tract of A.P. (Krishnaiah et al., 2006b) and later studies confirmed these findings (Jhansi et al., 2010). Afterwards there is absolutely no published evidence on the status of insecticide resistance in BPH in any of the rice growing tracts of India. Nevertheless practical indications for inferior effectiveness of imidacloprid against BPH have been noticed in many rice growing areas in Indian sub-continent by pesticide industry. Use pattern and intensity of use of neonicotinoids like imidacloprid, thiamethoxam and insect growth regulator insecticide buprofezin appear to be not uniform in different rice growing tracts of India. So intensive studies are likely to give us insights into insecticide resistance spectrum of BPH populations present in different regions and also the possible source of migrants to Indo-Gangetic states including Haryana and Punjab. This is the only practical approach left to us for the purpose in the present movement of time.

**5. Mathematical models for assessing the long range migratory patterns of BPH:** There are several two-dimensional and three-dimensional mathematical models developed by Korean, Japanese and Chinese scientists which were extensively used for assessing source of migrants to Japan, Korea and China (Otuka, 2009). However the models involve critical and



detailed meteorological information up to 2500 meters above ground level during the monsoon period in addition to light trap catch data at the destination and likely source of migrants. It is advisable to use those methods only after getting initial indications from studies on insecticide resistance spectrum in different rice growing regions of India. Further, most of the studies using these mathematical models were done for BPH migrations for long distances in the sky above seas and oceans from China to Japan and Korea. This may not be of much practical value for Indian conditions as the migration here is by land route.

## CONCLUSIONS

1. Evidence on host plant resistance on BPH both historical and present clearly shows that our knowledge is far from adequate even to plan strategic development of resistant varieties. Main reason is the concept of the rice breeders in treating host-plant resistance to BPH just as any other trait and attempting to transfer just like that by bio-technological means. It clearly points that our plant screening for insect and also breeding techniques are inefficient.
2. Direct field screening and plant selection may be helpful to a greater extent to transfer the BPH resistance to locally suited susceptible varieties with all other desirable traits.
3. Proper Insecticide usage needs concerted efforts both in research front and equally and even more importantly on extension side in suitably educating farmers and administrators.
4. Usage of resurgence causing insecticides mostly synthetic pyrethroids by farmers due to their ignorance and more importantly by intentional prompting by pesticide personnel is the most important demonic thing that is crippling rice farmer. Stringent administrative regulations in this direction both in letter and spirit are urgently needed.
5. Special strategies of BPH management for different countries depending on the migration pattern of their local biotype are required. This is both in identification of source of migrants, the whole process of migration route and also all the likely consequences of the migration.
6. Non-traditional approaches need allotment of resources for research both at local and international

level. Many offshoots of these approaches may pave way for management of other sucking pests in other crops also.

7. A simple adoption of transplanting design suggested can form an inexpensive method for BPH management. This does not require additional resources by the rice farmer in terms of inputs or knowledge.

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