

Review Article

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## A Global Perspective of Rice Brown Planthopper Management I -- Crop-Climatic Requirement

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**Abstract** Rice Brown Planthopper, *Nilaparvata lugens* (Stal) (BPH) along with White-backed Planthopper, *Sogatella furcifera* (Horvath) (WBPH) have co-evolved along with rice plant during its domestication of thousands of years. These plant hoppers are small insects. The adults measure about 4-6 mm in length and 3-4 mm in width. The nymphs as well as adults suck plant sap from phloem and occasionally from xylem. Enormous draining of sap results in drying of plants in circular patches called "hopper-burn". Adults have two morphologically distinct forms 1) macropterous i.e. those with fully developed wings and 2) brachypterous i.e. those with half developed wings. Macropterous forms can move up to few thousands of kilometers and settle in favorable areas. The progeny develops into brachypterous forms capable of laying 300-400 eggs/female facilitating very rapid population build up. This process of morpho-form development is under hormonal regulation and genetically controlled. Distribution of BPH in the field is patchy or clumped i.e. "negative binomial distribution". East Asian, South-east Asian, and South Asian biotypes of BPH with distinct virulence patterns for host resistance exist. Long range migration of East Asian biotype from southern tip of China to Japan and Korea and back has been well documented. Possibility of such migration in South Asian biotype from Sri Lanka up to Punjab is hypothesized. South-east Asian biotype can possibly move from Indo-China countries up to tip of Indonesia and back.

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

### INTRODUCTION

Rice is basically a tropical crop. The critical mean temperature for flowering and fertilization ranges from 16 to 20°C. For vegetative growth a temperature range of 25 to 30°C and for grain filling and ripening 20 to 25°C was reported best. High temperature especially during night leads to loss of reserved food through greater respiration. For higher grain yield a day temperature of 25 to 32°C and night temperature of 15 to 20°C is preferable. Temperature beyond 35°C affects not only pollen shedding but also grain filling. A higher mean temperature ranging between 25 to 32°C per day would reduce the growth duration and accelerate flowering whereas a mean temperature of less than 15°C would slow down vegetative growth and plants fail to flower.

#### Rice growing seasons in different countries

Rice is mainly a crop of Asia. The fact that more than 90% of rice is grown and consumed in Asian countries

testifies this. If we observe the geographic positions of various rice growing countries, majority of them fall in tropical belt between 23.5° North Latitude (Tropic of Cancer) and 23.5° South Latitude (Tropic of Capricorn). In this zone, Sri Lanka, Thai Land, Indonesia, Malaysia, Philippines, Vietnam, Cambodia, Laos, Myanmar (Burma), Southern States of India Viz. Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Orissa, Maharashtra And Southern States of China Viz. Yunnan, Guangxi, Guangdong, occur.

In most of these areas rice can be grown in two or sometimes even more seasons by varying the sowing and planting time depending on local climate and temperature requirements of vegetative and reproductive stages of rice crop. This is typically called as tropical rice culture.

Rice is also grown in temperate regions comprising mainly Japan, Korea, Taiwan, Northern States of India

Viz. Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam, Chhattisgarh, Pakistan, Bangladesh And North-Eastern States Of China Viz. Hunan, Fujian, Zhejiang, Jiangxi, Jiangsu, Anhui, Shandong. In these temperate areas, rice can be grown only during one season from May to September end or first fortnight of October.

### **Rice Brown Planthopper, *Nilaparvata lugens* (Stal) (BPH)**

Among Sixty-five species of plant hoppers recorded feeding on Rice, Brown Plant hopper, *Nilaparvata lugens* (Stal) (BPH), White-backed Planthopper, *Sogatella furcifera* (Horvath) (WBPH) and Small Brown Planthopper *Laodelphax striatellus* Fallen (SBPH) belonging to Order Hemiptera, Suborder Homoptera, super family Fulgoroidea and family Delphacidae are the most economically important insect pests causing damage to rice crop. These plant hoppers are small insects. The adults measure about 4-6 mm in length and 3-4 mm in width.

General biology of all these three species is similar. Immediately after becoming adults, males and females mate. Mating is facilitated by substrate-transmitted acoustic signals from both males and females for coming together. These acoustic signals are reported to be specific to species and even distinguishable among different geologically isolated populations. The pulse repetition frequency of the male song is known to be involved in mate recognition and also to vary among geographical populations (Butlin, 1993). Parthenogenesis has not been reported and unfertilized eggs laid by females do not hatch. After mating ovarian development usually takes 4-6 days which is usually termed as pre-oviposition period. Microscopic eggs are inserted by females usually by piercing the leaf sheath with their ovipositor in batches of 30-80 per day. Oviposition period and number of eggs laid per female vary depending on temperature and nutritional status of the plants on which they are feeding. Egg period vary from 5-8 days and small whitish nymphs of about 1mm emerge. These nymphs as well as adults suck plant sap usually from nutritionally rich phloem and may occasionally on xylem mainly for their water requirement. Nymphs molt 5 times, each time

increasing in size and finally becoming adults. Total nymphal period vary from 15-22 days depending on temperature. Adult life span may vary from 7-15 days again depending on temperature and food availability. There are certain basic differences in the evolutionary status of these plant hoppers. Both BPH and WBPH are insects of tropical origin and appear to have co-evolved along with rice since its domestication. These are typically mono-phagous and can complete their life cycle only on *Oryza sativa*. These have optimum temperature requirement of 22-27 °C and cannot survive at a temperature below 10°C. BPH and WBPH can survive up to 45°C if allowed to feed continuously with host plant rice. But die within an hour if removed from feeding at such high temperatures. All their normal biological functions like feeding, speed of development and longevity are lowered while nymphal duration is prolonged if the temperatures are lower than the optimum range. More or less similar effects are observed if temperature increases above optimum range. However, speed of nymphal development may remain similar up to 33-35°C. BPH and WBPH are not known to over winter in any stage of their life cycle. Similarly aestivation during temperatures above 45°C has also not been reported. All these facts testify their co-evolution along with rice plant.

Contrary, SBPH appear to be a temperate species in its evolutionary cycle. SBPH feeds on many plants of winter season and a serious pest of wheat. It over winters during severe low temperature regimes. It takes an opportunistic attack on rice crop in spring after wheat is harvested in China, Japan, Korea and Taiwan. But fortunately SBPH was not reported to be a serious pest of rice in Indian subcontinent including Sri Lanka, Pakistan and Bangladesh.

### **Morpho Forms Of Planthoppers**

Adults of plant hoppers generally have two morphologically distinct forms 1) those with long or fully developed wings or macropterous adults and 2) those with short or half developed wings called brachypterous adults. Both the forms are present in males as well as in females in all the three hoppers but brachypterous males are rare in WBPH. Macropterous adults are capable of flying over long distances,

sometimes extending to hundreds or few thousands of kilometers. These are capable of withstanding starvation during the flight until they reach a suitable habitat, which is usually a freshly planted rice crop. However, the macropterous adults can lay substantially low number of eggs per female, usually in the range of 70-100. Thus, macropterous forms are evolved for migration from fields or areas where conditions are not favorable to the favorable areas. Majority of the nymphs emerging from the eggs laid by macropterous adults in the new habitat become brachypterous or short winged forms. These are robust and capable of laying 300-400 eggs/female. Majority of the nymphs from these eggs also become brachypterous adults enabling very rapid increase in population. At the time of first settling of macropterous forms, the insects are very sparsely distributed, usually 1-2 insects/10-100 hills. Within 2-3 generations, the populations raise to 40-100 insects/hill which is far above the economic threshold level of 10-20 insects/hill and can cause “hopper burn” if no control measures are adopted (Ding et al., 1987).

#### **Hormonal regulation of morphoforms**

Generally proportion of macropterous or brachypterous adults from 5<sup>th</sup> instar nymphs is influenced by many factors. Chemical composition of the rice plant is the most important factor affecting the wing-form ratio of BPH. Among different nymphal instars, supply of nutrients for 1st instar nymphs is important. Feeding of first instars on plants with poor nutrition during vegetative stage due to lower nitrogenous fertilizer application or on plants during senescence usually result in development of high proportion of macropterous adults, both males and females. Temperature and photoperiod are of secondary importance. Relative humidity and population density are not related to wing dimorphism. (Zhang Zeng-Quan 1983). However, recent studies have revealed that irrespective of external factors that promote macroptery or brachyptery, the whole process is under hormonal regulation and genetically controlled. Presence of High titers of juvenile hormone (JH III) above a threshold during 5<sup>th</sup> instar enable the individual to become brachypterous. The individual insects destined to become brachypterous adults maintain

much higher JH III levels from 2<sup>nd</sup> and 3<sup>rd</sup> instar onwards. These were amply demonstrated by external application of JH III disruptor called precocene II (Ayoade et al 1996; Ayoade et al., 1999). In BPH, JH-Esterase transcripts have been isolated from fat body and its role in regulating JH III levels has been demonstrated (Shuhua Liu et al., 2008).

#### **Damage to Rice Crop**

All the three species of hoppers possess typical piercing and sucking type of mouth parts usually called stylets. Stylets have a provision to insert into plant system particularly vascular bundles and drain enormous quantities of plant sap. As phloem contains nutrients like carbohydrates, aminoacids and peptides plant hoppers mainly derive their nutrition from phloem. Those occasionally feed on xylem vessels carrying inorganic nutrients like nitrates, potash, phosphates, calcium, magnesium, zinc etc. This probably is essential to satisfy their excess water requirement. Typical structures called stylet-sheaths are formed around the stylets at the time of feeding but remain inside the plant system or mainly vascular system. The stylet-sheaths cause serious obstruction to normal vascular flow in both phloem and also to some extent xylem. However these plant hoppers have not been recorded injecting any known toxins into rice plants that adversely affect normal plant physiology.

At genetic level it has been reported that planthopper feeding up-regulates the genes responsible for senescence and down regulates normal functioning. As a result affected plants start showing slight wilting symptoms at first followed by severe wilting and drying-up. The damage by BPH and WBPH spreads in a circular fashion and is technically termed as “hopper-burn”. If timely control measures are not taken up against the plant hoppers, the entire field could be hopper burnt in a span of 15-20 days. (Krishnaiah et al., 2002; 2006; 2007)

#### **Feeding preference among insect species and life stages**

There are differences in feeding preference among these species and feeding capability of different stages in their life cycle. Among the three species, BPH is capable of causing maximum damage per individual

insect and together with its very high fecundity it causes very high damage under field conditions in a given time. Among different life stages in BPH third and fourth instar nymphs have been reported to be more devastating than younger nymphs or adults. WBPH generally prefers to feed and develops relatively faster on younger rice plants in nursery or up to 30-35 days after planting. BPH prefers to feed on 45-50 day old plants.

### Field Distribution and Sampling

Field settling of BPH occurs in newly transplanted crop, in about 15 days after planting either by short range travel or long range migration depending on source area of the insect. At the time of initial settling, population is very low ranging from 1-5 insects per 100 hills or to a maximum of 30 insects per 100 hills. At this stage macropterous adults are randomly distributed in the field. They lay eggs on the same plants they settle or shift slightly to nearby plants after laying some eggs on original plant. Usually the nymphs that emerge are not uniformly distributed in a field or even in a small area of the field. Later, they move to nearby plants and become mainly brachypterous adults. By the end of second generation populations reach damaging levels if unchecked. During the third generation damage starts appearing in the field in circular patches and if unchecked may spread to whole field causing total "hopper-burn".

Distribution of insects on the whole is patchy or clumped. There will be very high population at some points and very low populations just nearby areas. This is statistically called "negative binomial distribution" (Ayi Kusmayadi et al., 1990).

Suitable and suggested sampling method for assessing BPH population in the field is random sampling in quadrats of four adjacent hills. Number of such quadrats can vary depending on stage of plants and required precision level. But practical experience of the author and many other workers showed that random sampling on fixed single hills at different stages is a better option. About 200 such hills fixed at random and distributed almost throughout the area can give a reasonably good estimate of BPH population in one acre field. However, for smaller plot sizes 20-25 fixed

random hills are sufficient. Economic threshold level for BPH has been suggested as 15-20 insects per hill and for WBPH 20-25 insects per hill after 45-50 days after planting. The values can be lowered to 10 insects per hill for BPH and 15 insects per hill for WBPH, if damage occurs in early stages.

### BIOTYPES OF BPH IN DIFFERENT REGIONS OF ASIA

BPH populations in Asia can be grouped into three biotypes: East Asian, South-east Asian, and South Asian (Sogawa, 1992). These populations have been shown to have different properties of 1. Insecticide susceptibility (Nagata 2002, Nagata et al 2002); 2. Wingform Response (Nagata and Masuda, 1980; Iwanaga et al., 1987) 3. Virulence for feeding on resistant rice varieties (Sogawa 1992, Tanaka and Matsumura 2000). BPH occurring in the region ranging from Northern Vietnam, China, and Korea to Japan belongs to the East Asian population (Sogawa 1992). BPH present in The Philippines, Thailand, Myanmar, Laos, Cambodia, Malaysia and Indonesia belong to South-East Asian biotype. BPH present in Indian Subcontinent, including India, Pakistan, Bangladesh and Sri Lanka can be designated as South Asian Biotype.

As early as 1977-78 when IR 26 the first BPH resistant variety released by International Rice Research Institute (IRRI), Philippines was tested at Directorate of Rice Research (DRR), Hyderabad, India and was found to be clearly susceptible. Later many varieties which are resistant at IRRI showed clear susceptibility at DRR and also at almost all BPH endemic locations in India. This took a dramatic turn and detailed studies conducted later clearly established that BPH present in Indian Sub-continent is different with regard to its virulence to resistant varieties for BPH at IRRI and also in many East Asian and South-East Asian countries.

### HISTORY AND DISTRIBUTION OF BPH IN INDIA

Though, BPH is associated with rice since 1900, large-scale field damage was reported for the first time in India during 1972 from Kuttanad area of Kerala. From 1973 onwards, its occurrence and damage in vast areas in farmers' fields was reported from



Krishna-Godavari delta of Andhra Pradesh, Cauvery delta of Tamil Nadu, Tungabhadra delta of Karnataka, Mahanadi delta of Orissa and vast areas in West Bengal particularly Chinsurah region. Almost during the same period, WBPH was noticed in North-Western parts of the country mainly Punjab, Haryana and Western Uttar Pradesh, although, the areas of occurrence and intensity of damage was low compared to BPH (Kalode, 1974 and Kulshrestha et al., 1974). The same situation continued almost for a decade or more. Meanwhile, efforts were intensified to evolve varieties resistant to BPH and a few of those were released for large-scale cultivation in endemic regions. These varieties found favor with farmers initially and adopted in some endemic regions. This probably resulted in reduction of BPH damage in some endemic deltas. But simultaneously, WBPH started appearing along with BPH in all endemic areas of A.P., Karnataka, Tamil Nadu, Kerala, Orissa and West Bengal. WBPH, however, continued to be important in Punjab, Haryana and Western Uttar Pradesh. This situation continued up to the year 2002-03. From 2005-06, there were sporadic but large-scale occurrences of BPH in Bihar, Jharkhand, Uttar Pradesh, Haryana and Punjab. From 2007-08 onwards, BPH attained number one pest status in the entire Indo-Gangetic belt stretching from West Bengal, Bihar, Jharkhand, Uttar Pradesh, Haryana and Punjab, although, WBPH was present in low numbers (DRR, 2010).

#### POSSIBLE REASONS FOR DISTINCTNESS OF SOUTH ASIAN BPH BIOTYPE:

- BPH existed in Indian subcontinent ever since rice cultivation was present in this area, i.e. more than thousands of years ago. But BPH became notorious only after green revolution with the cultivation of short statured, high N responsive, high tillering varieties providing suitable microclimate. Therefore, the distinctness of Indian BPH must have its genetic origin much before green revolution era.
- BPH in India might have undergone parallel evolution along with tropical indica rice in hot humid tropical climate present in South India and Sri Lanka the region to which most of the

rice cultivation was confined. During these few thousand years, the insect might not have had any genetic interchange with the BPH present in East Asia and South East Asia. Therefore, it preserved its genetically controlled virulence to some resistant genes in rice.

- Many of the tall indicas cultivated in India appeared to have possessed genes with moderate level of resistance to BPH. These resistant cultivars might have possibly exerted pressure on the insect to preserve its unique virulence.
- The main southwest monsoon prevalent in Indian subcontinent, can never cross Himalayas and move further north to China. Therefore, Himalayas appeared to have acted as a natural barrier for preventing Indian BPH populations from moving to China. During North-East monsoon from northern India BPH can move up to Sri Lanka only. This might have prevented the insect moving further south.
- Only for the last 5-10 years, there appears to be long distance migration of BPH either from Maharashtra region or from Orissa-west Bengal region towards Bihar, Jharkhand, Uttar Pradesh, Haryana and Punjab. Although, the exact reason for this is not very clear, it is probably an exploratory exercise as a part of innate nature of this insect to move even to very far off places in search of food wherever weather conditions are favorable. Secondly, cultivation of huge acreage under “boro” rice might also be aiding in exploiting the migratory nature of the insect.

#### LONG RANGE MIGRATION OF SOUTH ASIAN BIOTYPE OF BPH:

BPH cannot survive the severe winters present in Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand and northern parts of West Bengal from November to February as the temperatures are near freezing point or at times towards negative side. BPH cannot over-winter in egg stage. Further, there are no alternate hosts for BPH where it can survive and complete its life

cycle. Therefore, BPH must be migrating from southern or eastern parts of India during the months of May-June immediately after the harvest of rabi crop in southern or eastern states.

Southwest monsoon starts at the beginning of June every year in southern tip of India. It takes about a month for the full monsoon winds to be active throughout the country. The progress of south-west monsoon is all along the west coast from Kerala to Konkani region of Maharashtra, followed by Tamil Nadu and Karnataka, then Andhra Pradesh and Orissa, but cannot cross the Vindhya and Satpura mountain ranges present in Madhya Pradesh. Simultaneously, south-west monsoon also starts in Bay of Bengal and moves from coastal areas of West Bengal and Bangladesh and proceeds in north-westerly direction due to its inability to cross Himalayas. Both the halves of south-west monsoon meet somewhere in areas of Chattisgarh-Jharkhand-Bihar borders and move in north-westerly direction. Thus, the movement of south-west monsoon winds is northwesterly in direction from West Bengal through Jharkhand, Bihar, Uttar Pradesh and then finally reaching Haryana and Punjab.

From 1972, up to early 1990s, WBPH was the major problem in Punjab and Haryana probably because the macropterous adults of WBPH could move along the first south-west monsoon winds moving from West Bengal towards Punjab and Haryana in a north-westerly direction. It is well known that when compared to BPH, WBPH is more migratory and does not settle even if suitable host plant, viz. rice crop is available. It easily moves forward along the winds even with slight macroclimatic disturbance due to winds. WBPH rarely settles to the extent that it can multiply to the population levels that can cause economic damage to rice crop. Hence, it could settle early in Punjab and Haryana, which are the final destination points of south-west monsoon. On the contrary, BPH is more sedentary and does not move forward unless the situation demands in terms of exhaustion of food sources by way of harvest of the crop. Hence, BPH was confined only to eastern parts of India apart from its southern strong hold. However, with large-scale cultivation of rice in boro season in the states of West

Bengal, Bihar, Jharkhand and Eastern Uttar Pradesh, rice crop is available to BPH in these areas up to April-May. More favorable climate exists in these states for the multiplication of BPH from February to May. Hence, BPH might have become one of the pests for “boro” rice in these areas similar to that of Bangladesh (Islam & Haque, 2009). Further, “boro” rice in these states might be serving as a temporary shelter for BPH migrating from Orissa and coastal areas of West Bengal up to the harvest of rice in April-May. Immediately after harvest of “boro” rice the time is also ripe for southwest monsoon which can take BPH up to Punjab and Haryana quite early in the kharif, i.e. in June, or early parts of July. This allows sufficient time for completion of 3 generations for BPH before the kharif rice is harvested in October end or first fortnight of November. Thus, “boro” rice might be helping for wide spread occurrence and damage by BPH in Punjab, Haryana and Western Uttar Pradesh.

After the harvest of kharif rice in September end or first fortnight of October, winter starts setting in the entire northern states of Punjab, Haryana, Uttaranchal, Uttar Pradesh, Bihar, Jharkhand etc. Then it is most likely that BPH migrates back to either eastern states of West Bengal and Orissa or even to the southern states of Andhra Pradesh, Karnataka, Tamil Nadu and even Kerala. Usually during this period, North-East monsoon starts and it might be helping the migration of BPH from northern states to eastern and southern states where it can have year round multiplication. North-East monsoon rains can take BPH only up to southern tip of Indian Peninsula and up to Sri Lanka. BPH cannot move further south of Sri Lanka as it has to cross the mighty Indian Ocean. There are no land areas or islands where rice is cultivated in the south beyond Sri Lanka. As the monsoon winds move mainly in North-South direction from one area to another area and not in East-West direction. This might also be responsible for isolating South-Asian biotype from South-East Asian biotype. All this is hypothetical till date. No studies have been carried out at the ground level. (Krishnaiah et al., 2011; Krishnaiah and Jhansi Lakshmi 2012.)

#### **MIGRATION OF EAST ASIAN BPH BIOTYPE:**

Migration of East Asian BPH biotype has been extensively studied. In fact the most fundamental

details of the whole long range migration of BPH have come into light through the efforts of Japanese rice scientists first and later by Chinese scientists. BPH migration here is mainly aided by East Asian Monsoon. The East Asian monsoon affects large parts of Indo-China, The Philippines, China, Korea and Japan. It is characterized by a warm, rainy summer monsoon and a cold, dry winter monsoon. The rain occurs in a concentrated belt that stretches east-west except in East China where it is tilted east-northeast over Korea and Japan. The seasonal rain is known as Meiyu in China, Changma in Korea, and Bai-u in Japan. The onset of the summer monsoon is marked by a period of pre-monsoonal rain over South China and Taiwan in early May. From May through August, the summer monsoon shifts through a series of dry and rainy phases as the rain belt moves northward, beginning over Indo-China and the South China Sea (May), to the Yangtze River Basin and Japan (June) and finally to North China and Korea (July). When the monsoon ends in August, the rain belt moves back to South China. East Asian biotype of BPH migrates from southern tip of China to eastern states of China by May end and then to Japan and Korea by June first fortnight along the Bai-u monsoon. In Japan and Korea rice crop is available in transplanted condition by May end. BPH settles, multiplies, damages rice crop up to August end or September first fortnight or September end. When rice crop is harvested in Japan and Korea by September end BPH migrates back to southern tip of China via the eastern states of China (Otuka, 2009).

#### **MIGRATION OF SOUTH-EAST ASIAN BIOTYPE**

There is no published information available about long range migration of South East Asian biotype of BPH prevalent in The Philippines, Myanmar, Vietnam, Cambodia, Laos, Thai Land, Malaysia and Indonesia. However, there is vast scope for long range migration of BPH in this region. This migration is probably aided by Indo-Australian monsoon. This consists of the Indian and South-East Asian summer monsoon that occurs from June to September, and the Australian and Maritime Continent monsoon that occurs in austral summer (October to February). During June to September, monsoon winds move from southern hemisphere to northern hemisphere. Usually from

Australia, towards Indonesia, Malaysia, Indo-China region of Thailand, Laos, Vietnam, Cambodia and probably Myanmar. During October to February monsoon winds move in just reverse direction along the heating maxima which moves entirely in southern hemisphere from indo-China region to southern tip of Indonesia. BPH is likely to migrate in both the directions. As rice is cultivated throughout the year in the entire region and due to lack of studies on long range migration of BPH in this region, all this information is still hypothetical.

#### **PROCESS OF BPH LONG DISTANCE MIGRATION**

BPH can usually move few meters in the same field when disturbed. The insects can fly few hundreds of meters to few kilometers from one rice crop area nearing harvest to another area where young rice crop is available. This small distance movement or short range migration or trivial migration involves the following steps (Kisimoto, 1976; 1984).

1. Movement of BPH (macropterous males and females) from plant base to the tip of crop canopy either at dawn or at dusk when the wind speed is low ( $< 5\text{m/second}$ )
2. Taking off into the blowing wind up to a few metres height (usually 5-15m)
3. Movement along the wind direction at this height for few meters to few kilometers
4. Landing to the fresh sites by downward movement.
5. Establishing the population at the new site.

However, long-range migration of BPH, which involves the movement of insects for few hundreds of kilometers up to even 2000 kilometers, is entirely different. In this case there will be mass movement of BPH usually in groups ranging from few thousands to few lakhs at a time during unfavorable conditions. The insects move to the tip of crop canopy either during dawn or dusk (Ohkubo & Kisimoto, 1971). From there, the insects make a slow upward movement until they reach up to a height of 750 to 2000 meters above ground level (Riley et al., 1991). Then, BPH will be above the cloud-forming zone of atmosphere. At this height, the insects are carried by forward movement of frontal-zones of hot humid winds of the monsoon. The movement will occur at a wind speed of 5-20 m/sec. In

this manner, BPH can move for about 25-45 hours to reach a destination, which is about 800 to 2000 km away. What environmental, physiological and behavioral factors determine the exact landing of the migrating insects is not very clearly understood even today. The physiological factors like exhaustion of reserve body energy or behavioral factors like oriented downward movement due to some environmental stimulus like humidity gradient or light source on the surface of the earth might be playing a role (Kisimoto, 1976, 1984).

### CONSEQUENCE OF BPH MIGRATION ON ITS MANAGEMENT

In Indian sub-continent, BPH populations present in Sri Lanka and southern states of India, viz. Kerala, Karnataka, Tamil Nadu and Andhra Pradesh and those present in eastern states like Orissa, Chhattisgarh and West Bengal might be migrating to Uttar Pradesh, Punjab and Haryana. Consequently, there is every likely-hood for genetic mixing of BPH populations present throughout the Indian sub-continent including Sri Lanka, Bangladesh and Pakistan. Similarly in case of East Asian biotype moving from China to Japan and Korea also, genetic mixing exists. This has tremendous implications on the management of BPH both in the origin and destination areas of long range migration.

For varied and obvious reasons, insecticides are extensively used for BPH management throughout Asian countries where this pest is a major menace. When an effective insecticide is extensively used in any area and the population develops high level of resistance against that particular insecticide, then that insecticide or the other insecticides with similar mode of action will be partially or completely ineffective in almost all the areas where that particular biotype migrates. This type of situation has already arisen with regard to resistance to imidacloprid a neonicotinoid in regions of south Asian and east Asian biotypes. Similar can be the case with regard to resistant varieties. When a resistant variety is released and extensively cultivated in one or two areas and BPH develops virulence against that particular variety rendering it susceptible. This can be extended to other varieties with similar genetic make-up with regard to BPH resistance in the entire region, where that biotype occupies through long range migration. This may not be evident in a short period

like one or two seasons but can be clearly seen after few years. This type of situation has already come to the surface in case of IR26 with BPH-1 resistance gene in East Asian and south-east Asian biotype existing regions.

### Dynamics of rice cultivation in china and its influence on BPH

Rice agriculture in China is characterized by the wide adoption of high-yielding F1 hybrids of rice. Since its introduction in 1976, hybrid rice spread rapidly to about half of the total rice area in China by 1990. Reportedly, a significant increase in rice production in the 1980s largely depended upon hybrid rice. However, it is also pointed out that the frequency of outbreaks of BPH and WBPH increased correspondingly with the spread of hybrid rice area in the 1980-90s in South China (Tang et al 1995).

### CONCLUSIONS

Basic studies on biology and ecology of Rice brown planthopper so far available are mainly from controlled conditions. Complete developmental patterns under field conditions can throw many insights in to our understanding about the pest.

More basic physiological studies on molting and wing form development are needed. Applied studies on utilization of the information so far available on wing form development for practical utilization in preventing formation of macropterous forms by application of juvenile hormone mimics towards harvest of rice crop can go a long way in preventing migration process itself. An economically viable technology development is needed in this direction.

Rice brown planthopper is an invasive species that has become a menace due to change in ecological factors in micro-ecosystem of rice crop. So many studies on quantification of these factors are urgently needed.

Studies on Long range migration of the pest in case of South Asian Biotype and South-East Asian Biotype will enable rice scientists to devise suitable strategies for management of BPH in these regions.

Studies on Gallbachina are another potential area which can make many inroads into BPH management strategy.



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