More than 20 species of planthoppers are found on rice worldwide (Table I). They cause hopperburn by their direct feeding and as vectors, transmit several viral diseases, indirectly. Only four species cause economic damage: the brown planthopper, N̄ilaparvata lugēns (Stål), the small brown planthopper, Laodelphax striatellus (Fallén), the whitebacked planthopper, Sogatella furcifera (Horvath) and the rice delphacid, Tarsoödes (=Sogaödes) orizicolus (Muir). The first of three species occur in Asia and T. orizicolus occurs in the southern USA and in the north central region of South America.

These planthoppers are members of Delphacidae, a family of Fulgoroidea whose members possess spur in the hind tibia. Other rice associated planthoppers are found in the Meenoplidae. (N̄isia nervosa (Motschulsky) in Africa and Asia) and the Lophopidae (Pyrrula perpusilla (Walker), the sugarcane leafhopper infesting rice in India) (Wilson and Claridge, 1991).

*N̄ilaparvata lugēns* (Stål):
- Brown planthopper (BPH)
- Asian rice brown planthopper
- Delphacidae: Homoptera

**Synonyms:** Delphax lugēns Stål,
- Delphax sordelescens Motschulsky
- N̄ilaparvata greēni Distant
- Kalpa aculeata Distant
- Delphax orichum Kirkaldy
- Delphax parysatis Kirkaldy
- Dicrironotopsis underida Kirkaldy
- Delphax oryzae Matsumura
- Hikona formosana Matsumura

The outbreaks of *N̄. lugēns* on rice crop have been recorded in Korea since 1924 (Okamoto, 1924) and in Japan since 1957 AD (Suenaga and Natkasaka, 1958). But it has become a major pest in many tropical countries in the Oriental region and some Pacific islands since 1960s only (Mochida et al., 1977). In the world 14 determined and two undetermined species are reported as the members of the genus *N̄ilaparvata* (Mochida and Okada, 1979).

*N̄ilaparvata* is defined on the possession of small spines on the first tarsal segment. Its species are distributed in three groups in Asia and the Pacific, in the Astrotropical region in South and Central America. But only in Asia and in Africa, species of *N̄ilaparvata* have been noted from rice. Among the Asian species, only *N̄. lugēns* is known as a rice pest; and in Africa, *N. metānder* has been found on rice. Other Asian species viz. *N̄. māri* and *N. bēkéri* are frequently collected on rice but their host plants are species of *Leersia*, a genus of grasses related to *Oryza* (Wilson and Claridge, 1991).

In addition, *N̄. albotrīsirīati, N. myērī* Muir, *N. chaeremon* Femnāh and *N. senwilīna* Melichar have also been recorded in various countries.

Damage to rice by BPH is both by its direct feeding and by transmission of Grassy stunt and Ragged stunt viruses.

**DISTRIBUTION**

*N̄. lugēns* is widely distributed throughout Southeast Asia and parts of the Pacific and Australia. It has been recorded from Australia, Bangladesh, Bhutan, Burma, Cambodia, Caroline and Marian Islands, China, Fiji, India, Indonesia, Japan, Korea, Laos, Malaysia, Micronesia, Nepal, New Caledonia, New Guinea, Pakistan, Papua New Guinea, Philippines, Sarawak, Solomon Islands, Soviet Maritime Territory, Sri Lanka, Taiwan, Thailand, and Vietnam (Mochida and Okada, 1979; Wilson and Claridge, 1991).
<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Distribution</th>
<th>Vector(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELPHACIDAE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>N. barkeri</em> (Stal.)</td>
<td>Brown planthopper</td>
<td>Southeast Asia and parts of the Pacific and Australia</td>
<td>Rice grassy stunt virus; Rice ragged stunt virus; Rice gray-stunt virus; Rice ragged stunt virus; Rice gray-stunt virus</td>
</tr>
<tr>
<td><em>N. muiri</em> China</td>
<td></td>
<td>China, Japan, South Korea, Taiwan West Africa</td>
<td></td>
</tr>
<tr>
<td><em>N. mwearon</em> Fennah</td>
<td>Whitebacked planthopper</td>
<td>The eastern Palaearctic; the Oriental; the western Pacific and Australia; The Ethiopian region; the southwestern portion of Palaearctic region and Madagascar</td>
<td>Rice gray-stunt virus</td>
</tr>
<tr>
<td><em>S. nigromaculata</em> (Muir)</td>
<td></td>
<td>Australia, the Oriental region; the Pacific, the Ethiopian region; the Atlantic and the New World; and the eastern Palaearctic</td>
<td>Dicistrostrum striae virus</td>
</tr>
<tr>
<td><em>S. rubrofasciata</em> (Kirkaldy)</td>
<td></td>
<td>The Palaearctic region; the Ethiopian region; Australia and the western Pacific</td>
<td>Maize rough dwarf virus</td>
</tr>
<tr>
<td>T. orizicolai (Distant)</td>
<td>Rice delphacid</td>
<td>Southern USA, Mexico, South and Central America, Central America, West Africa</td>
<td>Rice hoja blanca virus; Rice black-streaked dwarf virus; Rice</td>
</tr>
<tr>
<td>T. cubanensis (Crawford)</td>
<td></td>
<td>The Palaearctic and the tropical</td>
<td></td>
</tr>
<tr>
<td>Laodelphax striatellus (Fitch)</td>
<td>Smaller brown planthopper</td>
<td>Sri Lanka, Philippines, Indonesia, Vietnam</td>
<td></td>
</tr>
<tr>
<td>Harmitia vanthii (Fennah)</td>
<td></td>
<td>India, Korea, China, Taiwan, Soviet Far East Territory; The eastern Palaearctic region</td>
<td>Rice-stripe virus; Rice black-streaked dwarf virus; Rice black-streaked dwarf virus; Rice black-streaked dwarf virus; Northern rice mosaic virus</td>
</tr>
<tr>
<td>Udaleia suppresses (Matsunaga)</td>
<td></td>
<td>India, Sri Lanka, Philippines, Asia</td>
<td></td>
</tr>
<tr>
<td>U. adusta (Matsunaga)</td>
<td></td>
<td>Asia; Australia and the Pacific; Sri Lanka, Taiwan, Philippines; Fiji, Micronesia, Australia; The Nearctic and the Old World regions</td>
<td>Rice-stripe virus; Rice black-streaked dwarf virus</td>
</tr>
<tr>
<td>Tettigmina obliterata (Matsunaga)</td>
<td></td>
<td>China, Taiwan, Japan, Korea</td>
<td></td>
</tr>
<tr>
<td>Echitana cedon Fennah</td>
<td></td>
<td>India, Sri Lanka, Philippines</td>
<td></td>
</tr>
<tr>
<td>Sardi rufina Melichar</td>
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<td>Asia</td>
<td></td>
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<tr>
<td>Opterostrum sp.</td>
<td></td>
<td>Africa, Asia, Australia and the Pacific</td>
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<tr>
<td>Coronelius sinakana (Kirkaldy)</td>
<td></td>
<td>Sri Lanka, Taiwan, Philippines, Fiji, Micronesia, Australia</td>
<td></td>
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<tr>
<td>Toya proplana (Fiecher)</td>
<td></td>
<td>The Nearctic and the Old World regions</td>
<td></td>
</tr>
<tr>
<td>MEENOPLIDAE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nioia nervosa (Moedugsky)</td>
<td></td>
<td>Africa, Asia and Australia</td>
<td></td>
</tr>
<tr>
<td>LOFHOPIIDAE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyraula perpusilla (Walker)</td>
<td>Sugarcane leafhopper</td>
<td>Asia</td>
<td></td>
</tr>
</tbody>
</table>

* Major pest; ** Occasional pest

In India, BPH has been recorded in Andhra Pradesh, Bihar, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal (Ghose et al., 1960; Chelliah and Subramanian, 1972-73; Kalode, 1974; Bhalla and Payar, 1975; Diwakar, 1975; Channa Basava et al., 1976; Freeman, 1976; Nath and Sen, 1978; Verma et al., 1979).

**HOST PLANTS**

Rice is by far the most important host plant of the BPH (Dyck et al., 1979). However, a few
alternate hosts have been noted in the literature: Eleusine coracana (L.) Gaertn., Leersia hexandra SW., L. japonica Makino, Saccharum officinarum L., Setaria italica Beauv., Triticeum aestivum L., Zea mays L. Zizania eadweiglora Hand. A.K., and Z. longifolia (Nasu, 1967; Gris and Lever, 1969; Misra and Israel, 1970; Moehida and Okada, 1971). But several Oryza species have also been reported to serve as host plants for BPH in tropical Asia. Seven species, for example, are found in Indonesia: O. granulata, O. longiglumis, O. meyeriana, O. minuta, O. officinalis, O. ridleyi and O. nipponica (Mojohida and Okada, 1979) in addition to O. sativa. Other Oryza species such as O. australiensis, O. barthii, O. brachyantha, O. littifolia, O. nivara and O. punctata may also become potential host plants.

L. hexandra serves as a host for N. lugens in the Philippines (Heinrichs and Medrano, 1984). However, the population which occurs on L. hexandra is distinct from that on rice as it does not survive on L. hexandra. In addition, Leersia feeding population of BPH and rice-feeding BPH were shown not to interbreed when given a choice, primarily because of differences in the acoustic signals used during courtship. It was concluded that the Leersia-feeding population in the Philippines represents a distinct sympatric sibling species, differing in host plant preferences and in behaviour from the rice feeding populations (Wilson and Claridge, 1991). Similar Leersia-feeding populations of BPH have also been recorded from India, Sri Lanka, Indonesia and Australia (Claridge et al., 1988). In all the regions, the sympatric rice and Leersia-associated populations differ in acoustic signals and do not interbreed in the field. It is clear, therefore, that N. lugens should still be regarded as a very specific feeder, restricted only to rice, with a closely related species feeding and reproducing only on Leersia (Wilson and Claridge, 1991). But the Leersia population is important in the management of BPH on rice as it is attacked by the same predators, parasites and pathogens as the rice population (Heinrichs and Medrano, 1984).

**SYMPTOMS OF DAMAGE**

The damage to rice plants by BPH occurs directly by feeding of nymphs and adults and indirectly by the transmission of diseases. It is a typical vascular feeder primarily sucking the phloem sap leading to hopperburn. Fifth instar nymphs can suck the sap more than adults and adult females can suck more than adult males. During sustained feeding, BPH excretes a large amount of honey dew.

The appearance of damage to rice plants is variable according to the population density and stages of BPH, duration of feeding, cultivars, stages of rice plants and probably the presence or absence of water in the rice fields. BPH prefers rainfed and irrigated wetland fields to upland rice and direct sown fields to transplanted fields. It infests the rice crop at all stages of plant growth. At early infestation, round yellow patches appear which soon turn brownish due to the drying up of the plants (hopperburn). The patches of infestation then may spread and cover the entire field. Crop loss is usually considerable and complete drying of the crop occurs in severe cases. Wilting symptoms differ from those of plants under drought stress in which the leaf blades dry up with little loss of green colour (Sogawa and Cheng, 1979). The roots of attacked plants do not develop well and such plants can be pulled up very easily. No roots come out in hopperburned rice fields. The lower parts of the rice plants become blackish due to the development of Cladosporium spp. and Dematiaceae spp., more on plants covered by honeydew excreted by N. lugens. When the population of BPH is high, many moulded exuviae are usually found on the lower parts of rice plants and also on the surface of irrigation water. The plant tissue around egg-groups laid does not change from green to yellow in colour, distantly similar to that of S. furcifera (Mojohida and Okada, 1979).

The more probable cause of hopperburn damage is the reduction in the rate of translocation of photosynthates to the root system which results from the drain of the phloem sap and the physiological disruption of active transportation in the phloem by sustained feeding. Disturbance of the physiological activities of the root system enhances leaf senescence (Sogawa and Cheng, 1979).

Hopperburn usually occurs after heading in Japan (Suenaga and Nakatsuka, 1958), Korea (Okamoto, 1924), China (Lei and Wang, 1958).
Taiwan (Fukuda, 1934) and India (Velusamy et al., 1975). In Indonesia, on the other hand, hopperburn is found occasionally from seedlings in seedbed through rice plants just before harvest in lowland and mountain areas in both wet and dry seasons at some outbreak areas in Java (Mochida et al., 1977).

Besides, *N. lugens* is a vector of the virus diseases: grassy stunt and ragged stunt (Hibino, 1979; Chen and Chiu, 1981). Sheath blight incidence was high in BPH-infested plants (Lee et al., 1985). Similarly, seen rot caused by *Selevotium oryzae* Tulfis was more in BPH-damaged plants (Narayanasamy and Baskaran, 1979). In China, BPH is reported to transmit *Helminthosporium sigoideum* Car., also (Chiang, 1977).

**LOSSES AND FACTORS RESPONSIBLE FOR LOSSES**

A BPH outbreak in 1973 was reported as one of the most damaging insect outbreaks in the history of rice production in Japan. About 2.6 million persons were affected and 12,000 died from hunger (Okutani, 1980). BPH rice from the status of a secondary pest to a major yield constraint beginning in the 1960’s (Heinrichs and Mochida, 1984). In India, losses in 1975-77 were estimated at 365,000 metric tons of milled rice, equivalent to the annual consumption of 3 million people (Dyck and Thomas, 1979).

BPH outbreak has been recorded in several states of India (Gunathilagaran and Ganesh Kumar, 1977a). BPH was first observed in West Bengal only in 1968 and it occurred in outbreak proportions in the Hooghly district during 1973, 1975, 1976 and 1977 (Nath and Sen, 1978). In all, more than 6000 ha were affected. BPH was abundant in areas where the land was flooded, densely cropped and sprayed with contact insecticides in the early vegetative phase. At the grain filling stage, summer (boro) rice was more prone to BPH attack than winter (kharif) rice. Chatterjee (1969) reported the serious outbreak of BPH in two districts of West Bengal. Another outbreak in 1975 (Anon., 1975) has completely destroyed the rice crop.

BPH epidemics occurred once every few years in Tamil Nadu (Chelliah and Subramanian, 1972-73). The incidence was especially high in 1969 and 1971 due to late rain and high level of nitrogen fertilizers. Muddur district suffered heavy infestation during 1973-74 (Natarajan and Palcham, 1978). In Coimbatore district, about 200 ha of rice fields were severely hopperburned in 1975 wet season (Velusamy et al., 1975). BPH outbreak in 1983 in South Arcot district was attributed to drought with long spells of dry humid weather and delayed monsoon showers (Baskaran et al., 1983). Monsoon failure, application of double the dose of N fertilizers and quinalphos might have caused the BPH outbreak in Thanjavur district in 1987 (Natarajan et al., 1988). BPH as a pest was first reported in May 1975 only in Karnataka and in the same year, extensive BPH damage occurred in 10 districts during July-October (Channa Basavanna et al., 1976). Hopperburn was noticed in two districts of Himachal Pradesh in 1973 and 1974 (Bhalla and Pawar, 1975) and in 1973, several thousand ha were badly damaged in Orissa (Dyck and Thomas, 1979). BPH caused 20-25 per cent losses over 9000 ha in Andhra Pradesh in October 1959 (Anon., 1959). In the 1976 dry season, in East Godavari district, about 200 ha were hopperburned and 3,250 ha were severely infested (Prakasa Rao et al., 1976) and indiscriminate and repeated spraying of insecticides beginning with the early crop stage was responsible for the outbreak.

The most severe outbreak of the BPH in India occurred in Kerala at the end of 1973 and in early 1974 (Koya, 1974; Nalinakumari and Mammen, 1975). This was the first major outbreak of BPH in Kerala, in the 'Koil' lands of Trichur district and Kuttanad area in Kottayam and Alleppey districts. Economic damage was realised in 50,000 ha of rice fields (Freeman, 1976) and over 8000 ha of rice crop was completely wiped out (Gopalan, 1974). Moderate rainfall (160 mm) and a relative humidity of 85 per cent and a wider atmospheric temperature range of 20-33°C were thought to be responsible for the multiplication of BPH in Trichur area. Most crops showing damage had already headed (Kulshreshtha, 1974), although crops suffered some damage at all growth stages (Mammen and Das, 1973). In many fields, the damage was so great that growers abandoned the crop (Das et al., 1972). The
loss in grain yield ranged from 10 per cent in moderately affected fields to 70 per cent in those severely affected (Kulshreshtha et al., 1974). The estimated losses in Kerala from 1973-74 to 1975-76 total almost 12 million US dollars. The estimated loss was 12,000 metric tonnes of rice in 1972-73 and again in 1973-74 in the district of Ernakulam alone, a loss of 36,150 metric tonnes was estimated (Mathur, 1978). Uttar Pradesh experienced the BPH outbreak in kharif crops during 1973 (Srivastava, 1976) and 1977 (Verma et al., 1979) at the panicle initiation stage. More than 30,000 ha of rice crop in Bhojpur and Rohtas districts of Bihar was hopped burned in 1990 (Upadhyay and Diwaker, 1992). The amount of grain lost because of BPH infestation in the whole of India has never been estimated but it must be worth at least 20 million US dollars. But, by using Cremer’s (1967) calculation for yield loss, it was estimated that 1.8 million tonnes of rice was lost annually in only three states: Andhra Pradesh, Tamil Nadu and Orissa. At 150 US dollars/mt, that would be worth more than 277 million US dollars (Dyck and Thomas, 1979).

Several factors have been cited as contributing to the outbreaks of BPH (Kenmore, 1980). The major factors are:

• widespread planting of modern varieties (because they are short stemmed and high tillering with a better BPH microhabitat; uniformly susceptible as compared to previously resistant local varieties).

• increased use of nitrogen containing fertilisers (because it increases the nutritional value of the rice crop for BPH to speed up its growth and fecundity; encourages vegetative growth which provides favourable microhabitat for BPH)

• increased use of insecticides (because they directly destroy natural enemies which otherwise regulate the BPH population; destroy the food source of natural enemies causing further decline of natural enemy populations and tendering fields vulnerable to reinvasion of BPH; provide selection pressure for BPH to become resistant and cross resistant; stimulate reproduction if applied at sublethal doses; increase feeding rates at sublethal doses; accumulate in a resistant BPH and thus cause mortality of natural enemies further)

• rapid expansion of irrigation systems (because they create a moist microclimate preferred by BPH, allow more months of the year to be planted under rice; the sole food source of BPH, encouraging continuous population expansion; shorten the dry season when BPH population would be stressed by lack of food and expected to collapse; create poorly drained areas at the tail end of systems where ratoon and volunteer rice persist in larger populations than otherwise serving as hosts for BPH, and

• inadequate weed control (because they act as a bridge between rice crops or preferred stages of rice crops to sustain pest populations). But, except for insecticides and nitrogenous fertilisers, conclusive evidences are yet to be shown for the role of other factors that favour BPH outbreaks.

For example, dense planting increases populations of BPH (Hirn et al., 1970). The reason given by most researchers is that high relative humidity favours survival (Pillai et al., 1979). However, phytotron studies show that BPH mortality increases at humidities over 60 per cent perhaps because of increased pathogen infection. Two other explanations are: dense plantings provide more plant surface area and thus competition for oviposition or feeding sites (Kenmore et al., 1984) and dense canopies impede egg parasitic wasps (Shepard and Arida, 1986).

It is generally believed, that temperatures ranging from 28 to 30°C seems to be suitable for the development of BPH in the temperate zone (Mochida, 1964). In the tropics, a low relative humidity may be suitable for population growth when there is adequate irrigation water. When supplies of water are limited, a high relative humidity is favourable. Very heavy rain seems to increase the mortality of the first and second instar nymphs. On the other hand, it is also believed that fairly high temperatures and low rainfall conditions
are related to outbreaks (Abraham and Nair, 1975; Kulshreshtha et al., 1974).

LIFE CYCLE

Adult emergence takes place at the basal part of the plant. It begins at dawn and continues for 4-5 h.

Adult

The adult hopper is 4.5-5.0 mm long and has a yellowish brown to dark brown body. The wings are subhyaline with a dull yellowish tint. Adult BPH has two characteristic wing morphs: macropterous (long-winged) and brachypterous (short-winged). The long-winged macropterous adults (macropters) can fly and are responsible for migratory movement and colonisation of new rice fields. The short-winged, flightless, brachypterous adults (brachypers) can only hop within the field. The proportion of the two winged morphs within a given population fluctuates from time to time. However, the macropters dominate in rice fields at the time of colonisation, the subsequent two or three generations are largely brachypers, while towards crop maturity, the macropters become dominant again and disperse from the field. Wing morphology is influenced by several factors. Crowding during larval stage and reduction in the quality and quantity of food (Kisimoto, 1965), short daylength and low temperature (Johno, 1963) favour macroptery. Saxena et al. (1981) have shown a significant increase in macropterous forms among progenies reared on sensorous and hopperburned rice plants.

Adult males are attracted to female hoppers even from a distance of about 80 cm in the form of sexual communication by means of acoustic signals transmitted through the substrate (Ichikawa, 1976). Males cannot mate within 24 h of emergence and the ability to mate increases up to 5 days after emergence (Takeda, 1974). Courtship behaviour may be initiated by either sex. Both virgin females and mature males start emitting signals within a few minutes of settling on a host plant. The female call consists of simple intermittent pulses produced by the visible vibration of the abdomen. On receiving the signal, the male walks rapidly towards the female. If the female stops signalling; the male stops walking and starts sending its own signals until reciprocated by the female. The male call has a more complicated structure. It consists of repeated sections which themselves consist typically of three phases: (i) a series of 3-10 complex pulses, (ii) a series of regularly and rapidly repeated pulses and (iii) further complex groups of pulses. Thus, an alternation of male and female calls eventually leads the male to make contact with the receptive female and mating may take place (Claridge, 1983; Claridge et al., 1985). One male can mate with nine females in 24 h and a female more than two times in her lifespan.

Egg

The eggs are usually laid as egg groups in the leaf sheaths near the plant base or in the ventral midribs of the leaf blades. They are whitish or transparent, thrust in a straight line. They are covered with a dome shaped egg plug secreted by the female. Only the tips of the eggs protrude from the plant surface. The number of eggs laid at a site is varied: 2 to 3 in Japan, 4 to 10 in the Philippines and two to 12 in India. The average number of eggs laid was 244/female with brachypterous females laying 300-350 eggs and macropterous females laying less than that (Table 3).

Egg stage lasts for 6 to 9 days in the tropics. Nymphal period usually ranges from 10 to 18 days. N. lugens has five nymphal instars and the instars are distinguished by the shape of meso- and metanotum and body size (Moelkida and Okedra, 1979).

Table 2. Biology of N. lugens

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-oviposition period</td>
<td>1-4 (Brachypterous male) / 1-8 (Macropterous male)</td>
</tr>
<tr>
<td>Oviposition period</td>
<td>11-30 (Brachypterous female) / 6-12 (Macropterous female)</td>
</tr>
<tr>
<td>Incubation period</td>
<td>6-9</td>
</tr>
<tr>
<td>Nymphal instars</td>
<td>3</td>
</tr>
<tr>
<td>Nymphal period</td>
<td>10-18</td>
</tr>
<tr>
<td>Total life cycle</td>
<td>19-23</td>
</tr>
<tr>
<td>Adult longevity</td>
<td>14-21 (Male) / 14-30 (Female)</td>
</tr>
<tr>
<td>Fecundity</td>
<td>300-350 (Brachypterous female)</td>
</tr>
</tbody>
</table>

* When reared on susceptible plants.

Adapted from several sources.
Nymph

Freshly hatched nymph is cottony white, 0.6 mm long and it turns purple brown and 30 mm long in the fifth instar.

Adult longevity varies between field populations (9.0 days) and laboratory populations of BPH (37 days). The pre-ovipositional period, on an average, is three to four days for brachypterous females and three to eight days for macropterous females. At natural temperature (25-30°C), total lifecycle takes 19-23 days. Temperature plays a major role in the lifecycle of BPH. The threshold temperatures of embryonic and post-embryonic development of the BPH are 10.8 and 9.8°C respectively (Suenaia, 1963). Egg hatching and survival is also more at 25°C. Eggs are highly sensitive to desiccation and soon shrivel when the host plant starts wilting (Kisimoto, 1977). Adult longevity and rate of oviposition is also influenced by the temperature conditions of nymphal stage (Mochida, 1964). A temperature range of 28 to 30°C during day time is ideal for the population development of the BPH. In warm and humid climates of the tropics, BPH remains active throughout the year and the population fluctuates according to the availability of host plants, activity of natural enemies and other environmental factors prevailing in the locality. In India, the peak population is observed during the late rainy season from October to November. Another peak appears during the dry season from April to May in regions where double cropping is widely practiced. In Japan and Korea, macropterous adults immigrate into rice fields from late June to early July every year. Afterwards, BPH spends several generations on rice and moves or dies at the end of the cropping season.

BPH spends several generations during the cropping season on irrigated rice in the Asian tropics depending on the duration of the crop. It completes five generations on one rice crop in southern Japan (Mochida, 1964), 5 to 6 generations in Central China (Lai and Wang, 1958) and 4 to 6 in Indonesia (Mochida et al., 1977). There are usually three generations on the modern high yielding varieties in the tropics (Heinrichs et al., 1986).

BPH is known to make wind assisted migratory flights each year to colonise the summer rice growing areas of China, Japan and Korea (Kisimoto, 1976) whether it migrates elsewhere is less certain (Kisimoto and Dyck, 1979) but the capture of the specimens over the sea between the Philippine Islands (Saxena and Justo, 1980) supports the hypothesis that it is a migrant throughout its range (Rosenberg and Magor, 1983a). Field and laboratory observations suggest that BPH take-off at dusk and that some continue flying for up to 20-24 h if the temperature is more than 17°C. Long distance migration can occur in surface winds when they are strong but long distance migration is more likely at 1.5 km (Rosenberg and Magor, 1983b).

MANAGEMENT

Mechanical/Physical

A traditional method to control BPH is to pour 30-40 l of kerosene per ha onto a flooded field (Suenaia, 1966). In a young crop, two men can drag a rope across the foliage bending it into the kerosene film on the water (Mista, 1919). Older rice plants are beaten with bamboo poles or branches or brushed with a rope soaked in kerosene to dislodge insects into the oil. Most insects are killed if the operation is done early in the morning when the insects are lethargic after raising the water level as high as possible. This technology dates from the 1600s in Japan where whale oil was used before kerosene became available. A kerosene film is made more toxic if mixed with pyrethrum. Fields were drained after six h to prevent phytotoxicity. Oil films on the paddy water are highly toxic to many predators and may have caused resurgence of BPH (Kenmore et al., 1984).

Sweeping rice plants with nets, bags or baskets coated with sticky materials (jack fruit latex, castor oil, grease) has been used to remove BPH in olden days (Miller and Pagden, 1930). Light traps are said to control planthoppers. Greater numbers of hoppers are collected during a full moon. At peak adoption of this method in 1930s, over one million traps were set out 1-1.5 m above the crop canopy in China (one trap per 2.3 ha) and in Japan (20 traps per ha). As further proof of the value of light traps, pest outbreaks have been reported to occur in our
country after power blackouts because many insects are normally killed at street lights (Israel and Sheshagiri Rao, 1954). But the use of light traps to control insects has been criticized for many reasons: high cost, theft, erratic attraction and killing of beneficial insects (Litsinger, 1994).

Cultural

Draining the field is a common practice to control the planthoppers including BPH (Das and Thomas, 1977). Draining the field is reported to harden the plant tissue making the crop more resistant to insect feeding. Calcium is readily taken up when the field is drained which may be an explanation for this observation (Litsinger, 1994). BPH can also be controlled by alternate flooding and draining. Draining minimizes BPH incidence if carried out for 5-7 days but reflooding is necessary to control weeds and prevent crop desiccation. Frequency of the action is important because alternate flooding and draining causes high losses of nitrogen. The degree of control is enhanced by other management factors acting at the same time. BPH outbreaks are also frequently associated with certain cultural practices, such as irrigation, mainly by increasing host plant availability through the practice of double and triple cropping (Kenmore, 1980). Natural enemies may be able to track population increases associated with some of these practices but the extensive use of insecticides along with these other practices precludes any conclusion concerning their effect on the pest-natural enemy interaction and its subsequent influence on outbreak. Oka (1979) has proposed the use of synchronous culture of rice and a defined rice-free period within regions and help reduce BPH densities. This practice may also reduce the effect of specialist natural enemies, such as Anagrus spp., without consideration of alternate hosts during the rice-free period. In addition, the use of rice-free periods may interrupt the numerical response of generalist predators, such as spiders, in response to BPH densities (Kenmore, 1980). Current knowledge is insufficient to predict the outcome of interaction between cultural practices and biological control for BPH.

Planting rows oriented north-south lessens interplant shading and consequently is said to reduce BPH incidence (Oka, 1979). The trap-crop technique relies on the attraction of insect pests to plantings other than the main crop (Isley, 1951). Timing is important in utilizing a trap crop as the pest should not be allowed to reproduce. A trap crop should not sacrifice the field area. A final technique, only tested experimentally, is to plant 2-3 border rows of a field ahead of the main crop in a highly susceptible cultivar to attract BPH (Saxena and Joshi, 1984). The border areas are then sprayed. The problem with earlier plantings is that more extended water delivery is required; the pest-free fallow period is reduced and synchronous planting is less effective.

Split application of nitrogen, first with a basal soil application for slow release and using judicious amounts to help meet the dual goals of high yields and low pest incidence (Israel and Prakasa Rao, 1968) is also recommended for BPH management. Because, the beneficial effect of nitrogen on plant yields outweighs the pest controlling effect of entirely omitting its use (Oka, 1983). Potassium suppresses BPH populations through higher protogynes in plants, a physiologic phenomenon correlated with the elimination of amino acids and reducing sugars in the sap and the greater production of allelochemicals, thicker cell walls and greater silica uptake (Baskaran, 1985).

Tillage soon after harvest prevents unwanted crop growth (volunteer ration) which perpetuates BPH (Sakinasita and Koide, 1971). Stubble burial kills the ration to stop pest cycles, particularly monophageous pest like BPH, it carried out commonly wide. Stubble burial should be combined with synchronous planting for best results.

Host plant resistance

Distinct differences in levels of resistance to the BPH under greenhouse conditions were first observed at IRRI in 1963 (Pathak et al., 1969). Hence, a systematic evaluation of the world collection of O. sativa began in 1967 and by 1986, 400 accessions out of 50,000 accessions screened have been identified as having resistance to X. luteus (Raptasus and Heinrichs, 1987). Most of the resistant accessions are from India and Sri Lanka. In addition, 132 wild Oryza spp. accessions have been identified as resistant (Heinrichs, 1988).
Breeding programmes for BPH resistance have been established in most of the Asian countries and numerous varieties have been released since that of IR 26 in 1973 (Heinrichs, 1994). In India, many BPH resistant varieties, viz., Jyothi, Co 42, Parjai, Bharti, Shakti, Sonasali, PY 3, Suraksha, Sagar-Samba, Chandan, Vajram, Prahliba, Chaitanya, Krishnaveni, Nandi, MTU 4870, Bhadra, Asha, Pavizhvan, Karthika, Aruna, Makam, Reinya, Kanakani, and Udaya have been released. But, biotype selection in BPH has impeded the development of resistant varieties in many areas. Resistant rice sources identified in India have been listed recently (Gunathilagaraj and Ganesh Kumar, 1997b).

Biological

The role of natural enemies in the management of BPH and WBPH and the research needs to realise the full potential of biological control of hoppers have been highlighted recently by Gunathilagaraj and Ganesh Kumar (1997c).

Chemical

Insecticides effective against BPH include chlorpyrifos, isopropcarb (Velusamy et al., 1978), carbofuran, quinalphos, phosphamidon, chlorpyrifos (Rao and Rao, 1979b), carbosulfan (Pillai et al., 1983) BPMC (Patnaik et al., 1986), monocrotophos (Sanguttavan and Gopalakrishna, 1990), ethofenprox (Krishnaiah and Reddy, 1992), plant extracts from the roots of Eclipta alba, leaves of neem and Bacillus thuringiensis (Rao and Rao, 1979c), neem oil and other neem based products (Jena and Dani, 1994) and others. As insecticides were reported to cause resurgence of BPH, plant products are now increasingly exploited for BPH management. Neem oil treatment disrupted normal courtship signal emission and the mating behaviour of BPH females (Saxena et al., 1993). Neem oil and a few of the neem products are phytotoxic to rice plants above one per cent concentration. Older plants (above 60 days) could tolerate foliar sprays up to two per cent concentration (Jena and Dani, 1994).

Success of insecticidal treatments is dependent on several factors. Proper placement of foliar sprays is important in obtaining effective control. BPH feeds primarily at the base of rice plants and hence insecticidal sprays applied above the canopy often provide poor control of BPH. High reproductive capacity and oviposition behaviour renders the insecticidal control of BPH very difficult. As eggs of BPH are inserted into the stem tissues at the base of the rice plants, insecticides with ovicidal action can be used to kill eggs. Rao and Rao (1979b) reported that carbofuran applied on paddy water and BPMC, carbaryl and isopropcarb applied to water or soil inhibited egg hatching.

Careful and appropriate timing of application is the simplest way to enhance insecticide effectiveness. Kiratani (1972) suggested that appropriate timing will achieve insecticide specificity. As eggs of BPH are difficult to kill, it is best to apply insecticides when the majority of the nymphs are in the third or fourth instar stages. In the People's Republic of China, three BPH generations occur on the first crop and damage is caused by the third generation. Most effective control was obtained by treating the second generation (Anon., 1977).

Timing of insecticide application should take into consideration the natural enemy population in the field. As most of the insecticides eliminated natural enemies, Heinrichs et al. (1981) suggested that, based on light trap catches and field surveys, the best time to spray for BPH is about two weeks after peak trap catches, provided the economic threshold has been reached. Use of appropriate insecticide at the economic threshold level (ETL) places BPH control on a sound economic basis with minimum ecosystem disruption. In different countries, various ETLs have been reported. Sellammal Murugesan and Chelliah (1982b) reported that an average of 2.5 insects per tiller resulted in severe economic damage in a susceptible variety TN 1, while even a mean of 2.6 insectstiller did not cause economic damage in a moderately resistant variety Co 42. They further reported that the damage in the resistant variety ASD 11 was low at the above population levels. Thus, it is necessary to develop ETLs depending on the level of resistance in a variety. Sellammal Murugesan and Chelliah (1982a) further observed that in moderately resistant varieties, Co 42 and Triveni, at the same level of BPH population, the
yield was relatively lower in 60-day old plants than that of 45-day old plants. Thus, it is suggested that the ETL should be assessed taking also into consideration the level of resistance of the variety, stage of the crop, the natural enemy population and the climatic conditions that prevail in the region (Chelliah and Bharathi, 1994).

Additional factors that complicate the use of insecticides in the control of BPH are (Chelliah and Bharathi, 1994):

☆ the BPH is a phloem feeder and systemic insecticides move primarily through the xylem. Insecticide accumulates in the leaf tips and little of it accumulates in the leaf sheath area where BPH feeds.

☆ it is extremely difficult to control adults migrating from adjacent outbreak areas. Even when fields are sprayed, the insects are capable of laying eggs before they are killed. Many insecticides do not kill the eggs and when they hatch, the residual activity of the insecticide is not sufficient to kill the hatching nymphs and, thus additional applications are required.

☆ because of the high reproductive rate, BPH rapidly develops resistance to insecticides.

☆ many insecticides applied at sublethal rates cause BPH resurgence. Because many farmers use sublethal rates, these insecticides have caused serious problems.

☆ physiologically different BPH populations or biotypes have differential susceptibility to the commonly used insecticides such as carbofuran, metalaxyl, diazinon and methyl parathion in contact toxicity tests.

Insecticide-induced resurgence of BPH was common in the 1970s and 1980s with reports from every rice producing country in tropical Asia (Heinrichs et al., 1982; Shepard et al., 1990). The degree of resurgence is dependent on an interaction of factors consisting of the insecticide and its effect on the rice plant, the BPH populations and the natural enemies of BPH (Heinrichs and Mochida, 1984). Almost all groups of insecticides can cause resurgence. Insecticide type and rate, timing of application and the number and method of insecticide application, all influence the degree of BPH resurgence. Factors contributing to BPH resurgence consists of direct, effects of the insecticides on the BPH population and the indirect effects on the BPH population via the host plant and natural enemies (Chelliah and Heinrichs, 1980; Chelliah et al., 1980; Kenmore et al., 1984; Heinrichs, 1994). Chronic outbreak of BPH in Indonesia in the mid 1980s was attributed to the excessive use of insecticides in rice fields. The result was the Presidential decree in 1986 banning use in rice environment of more than 57 insecticides (England, 1987).

Integrated Pest Management

Pesticide management to enhance natural pest control by rice field predators and parasites, cultural control practices, the planting of resistant cultivars and non-chemical control measures form the IPM technology for BPH (Matheson et al., 1994). IPM technologies have been developed in different countries. All such programmes show that almost every decision about growing rice influences the crop's susceptibility to BPH (Table 3).

A typical IPM technology developed at the Tamil Nadu Agricultural University, Coimbatore (Regupathy et al., 1994) is as follows:

Table 3. Brown plant hopper control recommendations. (Matheson et al., 1994)

1. Grow no more than two rice crops per year
2. Choose early maturing plant hopper resistant rice cultivars
3. Plant neighbouring fields within three weeks of each other
4. Control weeds and do not exceed recommended rice plant density
5. Apply nitrogen fertiliser judiciously, with split applications three times during crop growth
6. Visit the fields weekly from seedling to dough grain stage; counting the pests and their natural enemies and taking control action when the brown plant hopper population reaches the economic threshold
7. Economic threshold for brown plant hopper: Nezara viridula, Philippines, 1986; one mature nymph per hill, subtracting five plant hoppers for each predator encountered
8. To reduce plant hopper populations, drain the paddy for three or four days
9. If draining the paddy is not feasible, apply an effective insecticide (one that does not cause resurgence) at the base of the rice plants only in the infested portions of the fields of the susceptible cultivars
10. Plough down volunteer rice after harvest

(Adapted from Reissig et al. (1985) and Smith et al. (1989))
avoid use of excess nitrogen

use resistant varieties like PY3, Co 42 and moderately resistant varieties like ADT 36

Provide rogue spacing at every two m to facilitate insecticide application

control irrigation by intermittent draining

set up light traps to monitor population and control BPH

avoid the use of insecticides causing resurgence such as synthetic pyrethroids, methyl parathion, fenithion and quinalphos

pre-flowering stage: Phosphamidon 85 WSC 500 ml, monocrotophos 36 WSC 1250 ml, phosalone 35 EC 1500 ml, chlorpyrophos 20 EC 1250 ml, carbofuran 3G 17.5 kg per ha

post-flowering stage: Carbaryl 10 D 25 kg/ha. Drain water before use of insecticides. Direct spray/dust towards the base of the plant.

Under Special Food Production Programme, the task force of the Directorate of Rice Research (DRR) recommends the growing of resistant variety Sonasali for BPH endemic areas in different stages. In addition, its recommendation includes application of insecticides based on the economic threshold levels.

_Sogatella furcifera_ (Horvath)

Whitebacked planthopper (WBPH or WPH)

(Delphacidae; Hemiptera)

Synonyms: _Delphax furcifera_ Horvath, _Sogata distincta_ Distant, _Sogata pallescens_ Distant, _Sogata kusunensis_ Matsumura and Ishihara, _Sogata tanonjienensis_ Qadri and Mirza

The whitebacked planthopper (WBPH), _Sogatella furcifera_ has had a long history as a pest of rice. Its damage to the crop was experienced as early as AD 697 in Japan (Suenaga and Natsuka, 1958). However, it was in 1899 that Horvath first erected the species _furcifera_ under _Delphax_ on the basis of a male specimen collected from Japan. The genus was subsequently changed to _Sogatella_ in 1963 (Fennah, 1963).

_Sogatella_ belongs to a group of genera that have a slender body shape, narrow vertex and frons and a white pale yellow longitudinal stripe from the head across the pro- and mesonotum. This group contains _Lathisria_, _Matusius_, _Sogatella_, _Sogatellana_ and _Tagesodes_ gen.n. Recently Asche and Wilson (1990) have reviewed the genus _Sogatella_ and related groups. According to them, _Sogatella_ species are found throughout the subtropical and tropical regions of the world. They are concentrated in Africa (13 species), Neartic and Neotropical regions (2 species) and Asia, the Pacific and Australasia (3 species).

_S. furcifera_ is second only to _N. lugens_ as a rice pest in Asia and other species such as _S. nigeriensis_ and _S. vibis_, though frequently found on rice (Amar, 1977; Amar et al., 1980) are not considered to be important pests at present. _S. vibis_ is the vector of maize rough dwarf virus in the middle east (Harpaz, 1966) and (as _S.longifurcifera_) is reported as a vector of Maize Stunt Virus by Greber (1982). _Skolophan_ is the vector of Difusiria striate virus in Australia (Greber, 1979) and dry bud rot of coconut in West Africa (Julia and Manau, 1982).

**DISTRIBUTION**

_S.furcifera_ is widely distributed in the eastern Palaearctic, the Oriental region, the Western Pacific and Australia (Wilson and Chtridge, 1991). It has been recorded in Australia, Bangladesh, Burma, China, Cambodia, Fiji, Hawaii, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Manchuria, Micronesia, Mongolia, Nepal, Pakistan, the Philippines, Ryukyu Islands, Saudi Arabia, Sri Lanka, Solomon Islands, Taiwan, Thailand, the USSR, Vanuatu and Vietnam (Gunatilagaraj, 1983).

The western limits of the distribution of WBPH are still unclear (Asche and Wilson, 1990). Species recorded from Africa, Europe or the New World as _S. furcifera_ proved to be other species, Similarly, those recorded from Europe, North Africa and tropical Africa concern either _S. nigeriensis_ or _S. vibis_. Records of _S.furcifera_ from the New World countries in most cases concern _S. molina_ or _S. kolophan_. The western-most populations of true _S. furcifera_ examined by Asche
and Wilson (1990) were from Pakistan and Saudi Arabia. Its closest relative, *S. nigeriensis*, is widely distributed in Africa and occurs sympatrically with *S. farinacea* in Saudi Arabia. However, no transition zone (hybrid belt or cline) between these two species has been found (Wilson and Claridge, 1991).

In India, WBPH attack on paddy was reported first from Surat, Poona, Purna and Nagpur as early as 1903 (Leffroy, 1903-04). Subsequently, it was observed in Bihar and Bengal (Fletcher, 1916, 1917, 1919), Jabalpur and other neighbouring districts in Madhya Pradesh (Berg, 1960). WBPH appeared for the first time in 1966 in Punjab (Jaswant Singh et al., 1988) and in Rajasthan in 1986 (Tripathi and Pandya, 1987). It is a major pest of rice in the Irrawaddy tracts of Uttar Pradesh (Sachan and Garg, 1992) and in Haryana after rice root weevil (Kushwaha et al., 1982). It attained higher level of incidence in Gujarat, Haryana, Rajasthan, Maharashtra, Madhya Pradesh and Punjab during mid-tillering phase in September/ October. However, it was reported earlier till early 1980s (Upadhyay and Diwakar, 1992). It has been recorded in Andhra Pradesh, Assam, Bihar, Delhi, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (Chelliah and Guanithalaguraj, 1990). In general, it is reported to be more severe in areas where resistant varieties of BPH have been grown.

**HOST PLANTS**

As compared to the BPH, *S. farinacea* has a wide range of host plants (Table 4). For example, it grows on *Echinochloa ghahresian* as well as *Oryza sativa*. It was observed to repeat some generations on graminaceous grasses: *E. ghahresian*, *Cynodon dactylon*, *Leersia japonica*, *Zizania aquatica* and *Glyceria acuiflora* (Suenaga, 1956). In India, it has been observed on rice, finger millet, sorghum, wheat, jowar and *Leersia hexandra*. The barnyard grass *E. crus-galli* var. *oryzoida* does not have antifeedant effect on WBPH which grows to become normal adults on grasses as on rice unlike BPH for which it is an antifeedant. Recently, the WBPH has been observed to breed on *Bergia cupressis* L. (Elainaceae) at Madurai, Tamil Nadu (Guanithalaguraj, unpublished).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Anthera aquatica</em> Sobol</td>
<td>Shri awn foxtail</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>Cynodon dactylon</em> (L.) Pers.</td>
<td>Stargrass</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td>D. decumbens Steud</td>
<td>Panche grass</td>
<td>Bhatkar (1964)</td>
</tr>
<tr>
<td><em>Echinochloa crus-galli</em> (L.) Link</td>
<td>Jungle rice</td>
<td>Mistry and Israel (1970)</td>
</tr>
<tr>
<td><em>E. crus-galli</em> var. <em>oryzoida</em></td>
<td>Barnyard grass</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>E. crus-galli</em> var. <em>maxima</em></td>
<td>Finger millet</td>
<td>Kimertel (1975)</td>
</tr>
<tr>
<td><em>E. crus-galli</em> var. <em>oryzoida</em></td>
<td>Foxtail millet</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>E. crus-galli</em> var. <em>punctata</em></td>
<td>Creeping Manna grass</td>
<td>Mistry and Israel (1970)</td>
</tr>
<tr>
<td><em>Hordeum vulgare</em> L.</td>
<td>Barley</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>I. hexandra</em> D. Sw.</td>
<td>Rice</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>J. japonica</em> Makino</td>
<td>Rice</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>Oryza sativa</em> L.</td>
<td>Rice</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>P. arundinacea</em> L.</td>
<td>Red Crown grass</td>
<td>Mistry and Israel (1970)</td>
</tr>
<tr>
<td><em>Psammochloa villosa</em> L.</td>
<td>Dwarf meadow grass</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>Sorghum bicolor</em> var. <em>pseudocereus</em> L.</td>
<td>Sugarcane</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>S. bicolor</em> (L.) Beauv.</td>
<td>Italian millet</td>
<td>Suenaga (1956)</td>
</tr>
<tr>
<td><em>S. vulgare</em> Pers.</td>
<td>Sorghum</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>Sparganium</em> elatinum R.</td>
<td>Australian wild grass</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>Tridax procumbens</em> L.</td>
<td>Wheat</td>
<td>Mistry and Israel (1970)</td>
</tr>
<tr>
<td><em>Zea mays</em> L.</td>
<td>Maize</td>
<td>Nasa (1967)</td>
</tr>
<tr>
<td><em>Zizania aquatica</em></td>
<td>American wild rice</td>
<td>Nasa (1967)</td>
</tr>
</tbody>
</table>
SYMPTOMS OF DAMAGE

The WBPH is usually more abundant during the early stage of the growth of the rice crop, especially in the nurseries. It attacks plants of less than four month old in the fields with standing water and shows a marked increase with the age of the crop. Rice is more sensitive to the attack at tillering phase than at the boot and heading stages. Damages caused by the immigrants occur soon after their landing through feeding and egg laying. Under favorable conditions, WBPH produces several generations and can cause "hopperburn" in the rice crop. Both nymphs and adults suck the phloem sap (Aucan and Baldos, 1982) causing reduced vigour, stunting, yellowing of leaves and delayed tillering and grain formation. Rice crop fails frequently to produce complete grains (seedless glumes) and a condition known as "red disease" in Malaysia. It is seldom that rice plants are killed by WBPH except early stages. However, yellowing of grownup rice plants has been reported. When the hoppers are present in large numbers late in the crop growth stage, they are seen infesting the flag leaves and panicles. Gravid females cause additional damage by making ovipositional punctures in the leaf sheaths. Feeding punctures and lacerations caused by the ovipositor predispose rice plants to pathogenic organisms and honeydew excretion encourages the growth of sooty mold such as Cladosporium spp. and Dematiaceae spp., but not so abundantly as in BPH (Mochida, 1964).

Symptoms of rice plant attacked by WBPH are variable according to population density, duration of feeding, rice cultivars and stages of the plant. Damage in the form of hopperburn frequently appears in large areas of a region comparatively uniformly in a rice field whereas it appears as circular patches in the case of BPH (Table 5). The sequence of development of symptoms by the feeding of WBPH is documented by Mochida (1982). Fortunately, unlike BPH, S. frugiperda is not a vector of any rice virus disease but was reported to be a vector of virus disease of Palang grass, Digitaria decumbens (Bisessar, 1966).

LOSSES AND FACTORS RESPONSIBLE FOR LOSSES

Outbreaks of WBPH have been recorded in recent times from several states in India (Gunathilagaraj and Ganesh Kumar, 1997a). Over 1000 ha of rice were hopperburned in Punjab during September 1983 (Saini, 1984) and around 8000 ha in Cachar and Karimganj districts of Barak valley in Assam during May-June 1985. This outbreak was favoured by high rainfall in early April followed by prolonged dry period with high temperature and humidity in May (Saha, 1986). Damage to early rice during 1983 in Manipur was attributed to the unusually heavy rains and flooding in the Imphal valley at that time (Barwal, 1984). In Karnataka, WBPH outbreak was reported during 1986 kharif in the Viseswaraya canal tract of Mandya. Higher N fertilisation (130 kg/ha) with

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>WBPH</th>
<th>BPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg period (days)</td>
<td>6.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Nymphal Period (days)</td>
<td>12.8</td>
<td>14.2</td>
</tr>
<tr>
<td>Adult longevity (days)</td>
<td>15.6</td>
<td>27.6</td>
</tr>
<tr>
<td>(Macropcteros female)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life cycle (days)</td>
<td>19.3</td>
<td>24.6</td>
</tr>
<tr>
<td>Feecundity (eggs/female)</td>
<td>around 300 (0-172)</td>
<td>300 (0-474)</td>
</tr>
<tr>
<td>Migration</td>
<td>longer distance</td>
<td>long distance</td>
</tr>
<tr>
<td>Hopperburn</td>
<td>uniformly over large areas</td>
<td>in circular patches</td>
</tr>
<tr>
<td>Vector of</td>
<td>only the nymphs found at the base</td>
<td>Grassy stunt</td>
</tr>
<tr>
<td>Distribution within the plant</td>
<td>and the adults invariably stay at the upper portion of rice plant</td>
<td>stunt</td>
</tr>
<tr>
<td>Ovipositional injury</td>
<td>plant tissue around egg groups changes from green to yellow colour.</td>
<td>does not change</td>
</tr>
</tbody>
</table>
frequent heavy rains might have favoured WBPH outbreak (Gubbiah et al., 1987). More than 80 per cent damage to rice is common in West Bengal in areas of water stagnation. Artificial infestation studies (Khatri et al., 1983) revealed that the grain loss varied from 11 to 39 per cent when 15 insects per hill was released at varying stages of plant growth. Yet precise estimates on the damage caused by WBPH and the resultant losses are yet to be quantified in the field.

Factors recognised to favour outbreak in different countries were degree of humidity (Miler and Pagden, 1930), low rainfall (Murata and Hirano, 1932), absence of typhoons during summer (Yashiro, 1939), average temperature and less rainfall (Kuwayama, 1940), increased sunshine in April-June (Mochida, 1964), transoceanic migration (Kisimoto, 1971), prolonged monsoon with intermittent rain and use of heavy doses of nitrogen (Majid et al., 1979). Weekly averages of 28.59°C, 69.55 per cent relative humidity, 8.18 h of sunshine and 0.71.7 mm of rain were reported to favour WBPH outbreak in Delhi (Garg and Sehni, 1980).

LIFE CYCLE

The life-cycle of WBPH has been studied by several workers (Atwal et al., 1967; Misra and Israel, 1968; Kittur, 1969; Vaidya and Kalode, 1981; Gunathilagaraj, 1983; Nalin, 1990). The description of the different growth stages of WBPH has been given by Atwal et al. (1967). The adult hopper can tolerate a wide range (8-36°C) of temperature and remain active. The macropterus females are more tolerant to temperature extremes than the males.

Adult

The adult hopper is 3.5-4.0 mm long and has a distinctive long narrow face. The forewings are uniformly, hyaline with dark veins. There is a conspicuous black dot about the middle of the posterior edge of each forewing which meets when the forewings come together. The pronotum is pale yellow, the body is black dorsally and creamy white elsewhere. There is a prominent white band between the junctures of the wings.

Macropterus males and females and brachypterous females are commonly found in the field, whereas brachypterous males have not been reported yet (Kisimoto, 1965). The eggs are commonly laid as egg-groups in sheaths when the rice plant is small but in the upper part of the rice plant when the plant is large. The number of egg masses laid by the WBPH is 85 per female and each egg mass contains 6 to 8 eggs. The eggs in a group are not sealed together by material secreted by the WBPH female, dissimilar to the BPH. The brachypterous females produced more eggs (300-350) than the macropterous females (164-300).

Eggs

Eggs are cylindrical in shape, laid on the plants with the micropylar end protruding from the tissue. The operculum is long and narrow (Nasu, 1957).

The incubation period varied considerably. It was 3.4 to 14 days in different countries. Nymphal period usually ranges from 8 to 28 days and there are five nymphal instars. The five different instars took 2-3, 2-3, 3-4, 3-4 and 2-3 days respectively to complete their development (Vaidya and Kalode, 1981; Gunathilagaraj, 1983).

Nymphs

Pale to light brown in colour and range in size from 0.6 mm when young and newly hatched to 2.0 mm after 11-12 days. Fifth instar nymph has narrow head and white or creamy white body. Dorsal surface of the thorax and abdomen marked with various amounts of grey and white markings.

The longevity of adult also varied from place to place (Table 6). It was 1.9 to 51.8 days for macropterus male, 2.0 to 41.1 days for macropterus female and 5 to 21 days for brachypterous male.

The average life cycle in India was 23 days at Cuttack (Misra and Israel, 1968), 11 to 56 days in the field and 24 to 34 days in the laboratory in Madhya Pradesh (Kittur, 1969) and 12.3 to 17.7 days in Punjab (Atwal et al., 1967). The generation time was prolonged from 20 to 91 days in Ludhiana, Punjab during winter (Shukla and Gupta, 1980). Temperature has a pronounced effect on the pre-oviposition period, duration of different stages and life-cycle.
Table 6: Biology of S. furcifera

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-oviposition period</td>
<td>2-5 (Macropterus female)</td>
</tr>
<tr>
<td></td>
<td>2-3 (2.7)</td>
</tr>
<tr>
<td>Oviposition period</td>
<td>3-12</td>
</tr>
<tr>
<td>Incubation period</td>
<td>6-7 (6.4)</td>
</tr>
<tr>
<td>nymphal instars</td>
<td>3</td>
</tr>
<tr>
<td>nymphal period</td>
<td>12-17 (14)</td>
</tr>
<tr>
<td>I instar</td>
<td>2-3</td>
</tr>
<tr>
<td>II instar</td>
<td>2-3</td>
</tr>
<tr>
<td>III instar</td>
<td>3-4</td>
</tr>
<tr>
<td>IV instar</td>
<td>3-4</td>
</tr>
<tr>
<td>V instar</td>
<td>2-3</td>
</tr>
<tr>
<td>Total life-cycle</td>
<td>18-24 (23)</td>
</tr>
<tr>
<td>adult longevity</td>
<td>151-318 (Macropterus male)</td>
</tr>
<tr>
<td></td>
<td>200-441 (Macropterus female)</td>
</tr>
<tr>
<td></td>
<td>500-210 (Brachypterus female)</td>
</tr>
<tr>
<td>Fecundity</td>
<td>2-425 (162)</td>
</tr>
</tbody>
</table>

MANAGEMENT

Mechanical

In olden days, WBPH was destroyed to a large extent by the use of field bags, by squirting kerosene in the infested fields and drawing a rope across the fields so as to get the nymphs as well as the adults in kerosene on the water. The cultivators also bagged their fields with illitaxes turned into temporary bags, previously moistened with a little kerosene (Mista, 1921). Sweeping rice plants with nets, bags or baskets; some coated with sticky materials (jack fruit latex, castor oil, grease) was also used to remove WBPH in Malaysia (Miller and Pagden, 1930).

Cultural

Draining of water from the field for about four to six days was found effective in controlling the build-up of population of WBPH by manipulating humidity (Patel, 1971). WBPH incidence was low when rice was intercropped with either soybean, pigeon pea or groundnut (Gangwar et al., 1994). Dryland rice intercropped with cotton or pigeonpea had also low WBPH population (Satpathy et al., 1977).

Chemical

Insecticides effective against WBPH are:

Carbaryl WP 0.5 kg a.i./ha
Endosulfan EC 0.35 kg a.i./ha
Diazinon G 1.25 kg a.i./ha
Phorate G 1.0 kg a.i./ha
Carbofuran G 0.5 kg a.i./ha

Carbofuran and triazophos are also reported to be effective: oxicides. The DRR recommends spraying of quinalphos, fenithion, chlorpyrifos, carbaryl, monocrotophos @ 0.5 kg a.i./ha or broadcasting of carbofuran 3G @ 0.75 kg a.i./ha or phorate 10G 1.25 kg a.i./ha, depending upon the stage of the rice crop. The insecticide application is recommended only when the population of WBPH exceeds the economic threshold level (10/hill during planting to mid-tillering stage; 5-10/hill during flowering and after). Pesticide application can be timed to coincide with the incipient outbreak of WBPH. In China, an expert system HOPPER for forecasting the outbreak of WBPH in the first crop season has been developed and HOPPER was able to make a reasonable prediction of WBPH attack in 1991 season (Tang et al., 1994).

As WBPH is not reported as a constant threat to rice production in India, effective IPM strategies are yet to be worked out. Under the Special Food Production Programme, the task force of DRR has implemented the IPM programme in 13 states and the measures recommended for other pests were found equally effective for WBPH also.

Other planthoppers attacking rice in India are:

- Nilaparvata lugens (Boisduval) (Delphacidae: Hemiptera)

- Ochthochara japonica (Fabricius) (Delphacidae: Hemiptera)

- Quinta grisea (Bouché) (Delphacidae: Hemiptera)

- Sogatella furcifera (Horváth) (Delphacidae: Hemiptera)

- Nilaparvata fulvata (Fabricius) (Delphacidae: Hemiptera)

- Sogatella furcifera (Horváth) (Delphacidae: Hemiptera)

- Ochthochara japonica (Fabricius) (Delphacidae: Hemiptera)

- Sogatella furcifera (Horváth) (Delphacidae: Hemiptera)

- Nilaparvata fulvata (Fabricius) (Delphacidae: Hemiptera)

- Sogatella furcifera (Horváth) (Delphacidae: Hemiptera)

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- Nilaparvata fulvata (Fabricius) (Delphacidae: Hemiptera)

- Sogatella furcifera (Horváth) (Delphacidae: Hemiptera)
Sogatella chenheae Kuch
Opicinsona verberlicia Distant
Delphacodes elegansissima Ishihara
Sogatella nebris Fennah

*S. kolophan* is the most widely distributed of all *Sogatella* species (Asche and Wilson, 1990) and is known from Australia, the Oriental region, the Pacific, the Ethiopian region, the Atlantic islands, the New World and the eastern Palaearctic. It is most commonly found in the tropics.

*S. kolophan* is small, slender, light yellow to straw-coloured plant hopper with hyaline forewing having grey or light brown markings in the apical half (Asche and Wilson, 1990). Its pest status on rice is yet to be established even though it has been frequently recorded on grasses. It is also reported as a vector of *Digitaria striate* virus in Australia (Gerber, 1979).

*Sogatella vixx* (Haupt)
(Delphacidae : Hemiptera)

Synonyms: *Liburnia vixx* Haupt
*Sogatella catapura* Fennah
*Sogatella diachenheae* Kuhl
*Delphacodes degens* Ishihara
*Delphacodes longifurcifera* Esaki and Ishihara
*Liburnia matsumurana* Mecalp
*Delphacodes panicicola* Ishihara
*Sogatella parakolophon* Liavanuori

*S. vixx* is widely distributed in the Palaearctic region, the Ethiopian region, the Oriental region, Australia and the Western Pacific. It is absent in the New World (Asche and Wilson, 1990). It has been recorded as a pest of rice in Egypt (Ammar, 1977). *S. vixx* is the vector of maize rough dwarf virus in the Middle East (Harpaz, 1972) and as *S. longifurcifera* has been implicated in the transmission of rhabdovirus of *Elsine rosea* in India (Yaraguntaiah and Keshavanaruthy, 1969).

*Laodelphax striatellus* (Fallen)
(Smaller brown planthopper
(Delphacidae : Hemiptera)

Synonyms: *Sogata striata* Fallen
*Delphax notula* Stal
*Liburnia devastans* Matsumura

*Lithurnia haupti* Lindberg
*Lithurnia nipponica* Matsumura
*Lithurnia nipponica* Matsumura
*Lithurnia nitonensis* Matsumura
*Lithurnia pterdactyla* Matsumura
*Lithurnia okashihens* Matsumura
*Lithurnia madonensis* Matsumura

*L. striatellus*, a severe pest of rice in Japan, China, Korea and southern Europe has been recorded in India also (Shukla, 1979). It is vector of black-streaked dwarf virus and stripe virus in maize. It is widely distributed in the Palaearctic from the UK where it is rare to Japan (Soviet Maritime Territory). In tropical Asia (Northern Philippines, North Sumatra), it is a pest on upland rice at higher altitudes (Wilson and Claridge, 1991).

*Unkanodes sapporonus* (Matsumura)
(Delphacidae : Hemiptera)

Synonym: *Unkana sapporona* Matsumura

*U. sapporonus* has been recorded from Korea, Japan, China, Taiwan, India and the Soviet Maritime Territory.

Adults of *U. sapporonus* are 3.5 to 4.5 mm long, pale yellow in colour with characteristic pale white stripe on the vertex and pronotum (Wilson and Claridge, 1991). It is a minor rice pest in Japan (Mochida and Okada, 1971) and is a vector of black-streaked dwarf and stripe viruses. But, it usually lives on maize, wheat and barley and is therefore, not important in the disease cycle on rice. It was recorded in India during December 1967 to March 1968 on rice under non-irrigated condition in the fields of Central Rice Research Institute, Cuttack in association with WBPH. It attacked the lower leaves which became greenish yellow, yellowish and then dried up completely (Mitra and Israel, 1968; Mism, 1975).

*Tagosodes pusana* (Distant)
(Delphacidae : Hemiptera)

Synonyms: *Sogata pusana* Distant
*Kelisia fiebreri-Muir
Unkana formosella* Matsumura
*Sogata striata* Quadri & Mirza
*Himenia chibana* Tian & Kuch
T. pusanus is a minor pest of rice in Asia and is known from India, Sri Lanka, Philippines, Taiwan, China, Indonesia, Malaysia and Pakistan (Wilson and Claridge, 1991). It resembles the WBPB but for the pattern of dark markings of the forewings.

**Eudellana celadon Fennah**  
(Delphacidae: Hemiptera)

**E. celadon** resembles the BPH in external appearance and size but for the dark brown veins on the forewings which are pale in BPH. It is rarely found in the rice fields of the Philippines, Sri Lanka and India (Wilson and Claridge, 1991).

**Nisia nervosa** (Motschulsky)  
(White streaked planthopper (WSPH))  
(Meconopidae: Hemiptera)

**Synonyms:** Livilla nervosa Motschulsky  
Nisia atrovenosa (Lethierry)

**N. nervosa** is a minor pest of rice in Africa, Asia and Australia (Grist and Lever, 1969). It has been found attacking sugarcane in China (Bangkun Huang and Qi Shicheng, 1981). Adults of *N. nervosa* are 2.7 to 4.3 mm long, grey coloured with characteristic granulate veins in the forewing claws and the tent-like forewings when folded over the body. Nymphs are rounded in appearance with head, dorsal plates and abdominal tergites light to dark grey. The mirid, *C. lividipennis* is an effective predator of *N. nervosa* and in Tamil Nadu, an unidentified nematode attacks *N. nervosa* during winter at Annamalainagar (Jayanthi et al., 1987).

**Pyrilla perpusilla** (Walker)  
(Sugarcane leafhopper)  
(Lophopidae: Hemiptera)

**Synonym:** Pyrops perpusilla Walker

**P. perpusilla**, a major pest of sugarcane in India, occasionally attacks rice fields situated near sugarcane fields, probably transgressing to rice when sugarcane was harvested (Wilson and Claridge, 1991). It was found attacking rice in Karnal and Sonapet districts of Haryana during August-October 1978-79 (Garg and Sethi, 1983a), Delhi during kharif 1976 and 1978 (Garg and Sethi, 1982) and Gurdaspur district in Punjab during August-September 1980. Heavy parasitisation of eggs (75-95%) by *Tetrastichus pyrillae* Crawford (Eulophidae: Hymenoptera) and nymphs and adults (20-60%) by *Epiprionica melanoleuca* (Fletcher) (Epiprypodidae: Lepidoptera) was observed in Haryana.

The egg and live cocoons of *E. melanoleuca* can be released in hopper infested rice fields @ 40,000-50,000 eggs/ha and 4000-5000 cocoons/ha respectively when the *Pyrrlla* population averages 3.5 individuals/leaf same as that of sugarcane threshold (Pawar, 1981).

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EFFECT OF PREMONSOON DRYSEEDING EMPLOYING RAINFALL PREDICTION IN VERTISOLS OF ARUPPUKKOTTAI TALUK

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ABSTRACT

Thirty one years of rainfall data of Arupakkottai in Virudhunagar district were analysed for variability indicated the "uni" model distribution pattern. Weekly rainfall prediction were made for dry seeding on vertisols. Thirty seventh ETD week (Sep 10-16) had the probability of 73 per cent for 20 mm rainfall. The probability for 10 mm of rainfall in the subsequent weeks remained more than 60 per cent. Dry seeding possibility in sorghum and cotton during 33 and 36th week has been indicated. A model with minimum assured rainfall at 50 per cent probability in conjunction with moisture availability index was developed and validated through on farm trials in the farmers' holdings. The yield increase in sorghum was 36 per cent over the monocrop crops. This technique was useful for other vertisol areas with uni rainfall pattern with primary peak in the month of October.

KEY WORDS: Rainfall prediction, dry seeding, vertisols.

In drylands, crop production is hampered by many constraints of which the rainfall is the major one as it forms the only source for soil moisture. Rainfall in the semi-arid tropics is not only low in quantity but also erratic and dependable in distribution. The length of growing season depends on date of receipt of rains for sowing and cessation of the same. Vinmani and Piarasingh (1986) defined the onset of sowing rain as that a rainfed crop could be sown during a week which received 20 mm of rain in one or two consecutive days provided the following week received 10 mm rainfall at 70 per cent probability. The end of rainy season could be identified as the week, provided the weekly rainfall of subsequent week fell below 0.25 times of PET continuously (Ramana Rao, 1988). The technique for dry seeding which involves the sowing of seeds in dry soil especially for vertisols has been developed to make use of the pre-monsoon showers received. Pothiraj (1982) reported that pre-monsoon dry seeding of raingfed cotton at 5th standard week at Coimbatore was optimum for higher yield. Keeping this in view, the rainfall data of Arupakkottai taluk in Virudhunagar district were analysed to determine the optimum week for dry seeding in vertisols.

MATERIALS AND METHODS

The historical rainfall data for 31 years (1959-89) were collected from the Revenue Department. The data were analysed for annual, seasonal, monthly and weekly variability through a computer programme (Chinnamurthi et al., 1991). Conditional probability for specific quantity of rainfall was worked out by adopting the method developed by Gopalaswamy et al. (1988). The resultant quotient was referred to 'Z' table for finding the probability. The initial probability (quantity of rainfall for fixed probability) was worked out for weekly data. The moisture availability index (MAI) was worked out as suggested by Hargreaves (1974).

The PET data worked out by Subramanian and Kulandaivelu (1986) were utilised. A model has been developed based on the minimum assured rainfall at 50 per cent probability for sorghum crop and validated in the farmers' holdings in the taluk at...