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The Brown Planthopper in India and Sri Lanka

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No.1 タイ国の米穀経済
2．インドにおける農業関係試験研究事情調査報告書
3．フィリピン，インドネシアにおける農業関係試験研究事情調査報告書
4．東南アジアにおける農業関係試験研究事情調査報告書
5．ヨーロッパ，アフリカにおけ農業関係試験研究事情調査報告書
6．沖縄における農業関係試験研究事情調査報告書
7．東南アジア等における森林資源およびその開発と利用
8．マレイシア，サバ州における農業関係試験研究事情調査報告書
9．戦前戦時における台湾農業技術の発達
10. 西アフリカ熱帯造林技術の発達
11. 北，中南米における農業関係試験研究事情調査報告書
12. インドネシア，フィリピンおよび台湾における畑作病害
13. パキスタンにおける農業および試験研究事情調査報告書
14. 中華民国(台湾)における農業関係試験研究事情調査報告書
15. タイおよびフィリピンにおける農業機械の利用研究事情調査報告書
16. 熱帯農産物の利用加工に関する研究事情調査
17. マレイシアにおける農業研究推進のための調査報告書
18. 東南アジアの畜産に関する調査報告書
19. フィリピン，インドネシアにおける畑作関係試験研究事情調査報告書
20. インドとの農業技術研究協力に関する予備調査報告書
21. フィリピンに発生しているココヤシのカダンカダン病に関する調査報告
22. 西部ジャワ水田地帯の農業経営実態調査報告
23. 水稲高収量品種の導入と農業経営
24. 沖縄の桑に関する調査報告書
25. インドネシアの豆類に関する生産および研究事情調査報告書
26. タイおよびインドネシアのトウモロコシベと病に関する調査報告書
27. 東南アジアにおけるイネノシントメタマバエの研究協力設立に関する調査報告書
28. フィリピンのマンゴー栽培地におけるミバエ類調査報告書
29. 沖縄におけるさとうきびを中心とする作付方式に関する研究
30. 東南アジアにおける香辛料の栽培加工に関する調査報告書
31. 熱帯畑作の開発に関する調査報告書(ブラジル)
32. 〃 (インドネシア)
33. Rice plant-and leafhopper incidence in Malaysia and Indonesia
34. 東南アジアの畜産
35. インド・スリランカ・タイにおける水稲害虫研究の現状
36. ブラジルの稲作
37. 熱帯畑作の開発に関する調査報告書―フィリピン―
38. セラードに関するシンポジウムⅢ抄訳
39. オーストラリアにおける牧草導入事情調査報告書
40. スリランカにおける水稲栽培の農業気象的研究
41. 東南アジアにおける雑草問題の現状と今後
42. ばれいしょ遺伝資源の探索，導入，保存と育種利用に関する調査報告書

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CONTENTS

THE BROWN PLANTHOPPER IN INDIA AND SRI LANKA

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This report describes the trip made by the author to India and Sri Lanka from October 24 to November 6, 1977. The major objectives of the trip were to: (1) get acquainted with the current status of the brown planthopper (BPH) problems in India and Sri Lanka and the related research activities, through interviews with BPH scientists and observations of their investigations, and (2) collect BPH specimens to study geographic variation with special reference to the difference in responses of the BPH populations to resistant rice varieties in the Indian subcontinent.

The trip was approved as a part of research activities conducted at IRRI in the framework of the collaborative project on biotypes carried out by IRRI and Tropical Agriculture Research Center (TARC), and supported financially by TARC.

The following four research institutes were visited during the course of the trip:

1. Central Rice Research Institute (CRRI), Cuttack, Orissa, India
2. All-India Coordinated Rice Improvement Project (AICRIP), Hyderabad, Andhra Pradesh, India
3. Central Rice Research Station, Pattambi, Kerala, India
4. Central Agricultural Research Institute (CARI), Peradeniya, Sri Lanka

The author would like to express his sincere appreciation to Dr. K.C. Mathur, Head of Entomology Division, and Dr. B.C. Misra, entomologist at CRRI; Dr. M.B. Kalode, entomologist at AICRIP, Mr. B. Thomas, entomologist at Central Rice Research Station, Pattambi; and Dr. T. Fujimura, TARC entomologist at CARI, for the generous support extended to him during his stay at each research institute.

The author also wishes to acknowledge the valuable information on BPH infestations in Tamil Nadu, India, communicated by Dr. S. Chelliah, Post-doctoral fellow, Entomology Department, IRRI, and Mr. R. Velusamy, Assistant Professor of Entomology, Agricultural College and Research Institute, Coimbatore, India. Dr. E.A. Heinrichs, and Mr. Peter Kenmore, Entomologist and Research fellow, Entomology Department, IRRI, respectively, are appreciated by the author for their critical reading of this report.

General information on BPH in India and Sri Lanka

This review is virtually based on information obtained through interviews with entomologists during the present trip and their published research articles, which cover the biology, recent epidemics, surveillance and control of BPH, and the varietal resistance of rice to this insect pest. The discussion concentrates on the background of recent outbreaks of BPH in India and Sri Lanka.

1. Biology

The life history of the insect has been studied at CRRI and College of Agriculture, Kerala [41,47]. The mating commences from the day of emergence to the adult stage. Oviposition starts from the second day after emergence and lasts up to 4 days. The egg-laying period varies from

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10 to 28 days. Number of eggs laid by a female ranges from 151 to 305, the average being 232. At CRRI, one female was recorded as laying up to 681 eggs during its life time. The average incubation period is 8.1 days. Each instar stage of nymph lasts usually for 2 to 4 days. The total life cycle from egg to adult stages takes from 19 to 23 days, the average being 21.6 days. However, 42 days were required for the development of the insect during the winter season at CRRI when the maximum temperature was 27.1°C and the minimum was 13.5°C. Male longevity varies from 14 to 21 days with an average of 18.4 days while female longevity ranges from 14 to 30 days with an average of 21 days. A temperature range of 25 to 30°C, and relative humidity of 70 to 85% are favorable for rapid development of BPH[38]. BPH outbreaks are not observed in Kerala during the autumn season (April-May to August-September), due to the deleterious effects of heavy rainfall and associated high humidity conditions[4,47]. It has also been observed that BPH populations are larger at lower temperatures and during bright sunshine periods and generally reach a peak when rainfall is absent or minimal.

The BPH develops 2 to 3 generations during each cropping season[38]. The population usually remains low during the vegetative stage or until about 60 days after transplanting[30]. It reaches damaging density in the third generation, which coincides with the ripening stage of rice[30]. In this connection, the planting of short-term varieties could eliminate the impact of large population resulting from the third generation developing on them[19]. It has been observed in Sri Lanka that most of the adults of 1st and 2nd generations are macropterous forms in spite of a very low population density, and the brachypterous forms generally appear in the 3rd generation[53]. It has been commonly believed that the macropterous females migrate from "grasses" to the newly planted rice, and migrate again to "grasses" with maturity and harvest of rice[38]. However, no alternative host plant has so far been discovered. Although it has been known that the BPH adults can survive for several days on certain species of weeds such as *Leersia hexandra*, no reproduction has ever been observed on them (M.B. Kalode, personal communication). The perennial wild rice, *Oryza perennis*, is considered to be an important cultural or alternative host of BPH during the off-cropping season.

Light traps generally record the highest peak during the late rainy season from October to November in most regions[6,7]. Another peak appears during the dry season from April to May in the regions where double cropping is widely practiced[7]. Population peaks are noted twice a year in each cropping season in Kuttanadu, Kerala[47]. However, the population does not rise to an alarming level during the first cropping season because of adverse climatic conditions. The highest peak appears usually in February coinciding with late growing stages of the second crop. The population trend shown by light trap record seems largely to depend upon the cropping pattern in each region.

Five species of hymenopterous egg parasites have been recorded in CARI, Sri Lanka (T. Fujimura, personal communication). Among them *Anagrus perforator* (Perkins) and a species of trichogramatid are dominant. The percentages of parasitism by these two species fluctuate greatly from season to season. There is no definite correlation between the population densities of BPH and the egg parasites. Nymphal and adult parasites belonging to Elenchidae, Dryinidae and Pipunculidae, and a mermithid nematode have also been studied at CARI[53]. Their parasitic activities are sometimes considerably high, but they are neither persistent nor able to control host population. A mirid bug, *Cyrtorhinus lividipennis* has been observed preying on the eggs and nymphs of BPH in Andhra Pradesh[46], Himachel Pradesh[57], Karnataka[40], and Uttar Pradesh[56]. In Andhra Pradesh, the seasonal abundance of the mirid bug on BPH has been surveyed in paddy free from insecticidal treatment[46]. The data indicated that the ratio of BPH to the mirid bug ranged from 3.5:1 to 7:1 during the vegetative growing stage of rice. However, the population development of the mirid bug exceeded that of BPH as rice maturation progressed, the maximum being 1:2.2. Similar population dynamics of the mirid bug has been recognized in Mandya, Karnataka [39]. Further studies on the utilization of *C. lividipennis* for biological control of BPH are in progress at CRRI and AICRIP, where a large number of *C. lividipennis* are successfully reared to prey upon the eggs of BPH.

Large numbers of a ladybird beetle, *Coccinella arcuata*, were found feeding on the nymphs of BPH in Kerala in 1973 [2, 3]. On the average, the freshly emerging 1st instar larva eats 1st and 2nd instar nymphs of BPH at a rate of 15 per day. The second, 3rd, 4th and 5th instar larvae and the adults consume all nymphal stages of BPH at a rate of 18, 25, 27, 29 per day, respectively. The adults occasionally feed on adult BPH. In the absence of BPH, this ladybird beetle is reared easily on alternate hosts, the legume aphids such as *Aphis craccivora* and *Rhopalosiphum maidis*. Planting cowpeas on footpaths between paddy plots is practiced at the Central Rice Research Station in Pattambi to provide a habitat for the predacious ladybird beetles.

About twenty species of predacious spiders have been recorded on BPH at CRRI [65]. Of these, salticid and lycosid spiders appear to play an important role in keeping down the BPH population. It has been observed that a single adult salticid or lycosid spider can eat an average of 18 to 20 adult BPHS.

2. Recent outbreaks

The BPH was first recorded in Sri Lanka as early as in 1912 [19] under the name of *Nilaparvata greeni,* and in Bengal in 1917 [8]. Its first occurrence in a pest form was reported from Tenali area, Andhra Pradesh in 1927 [72]. In 1935 and 1942 there were extensive outbreaks in the deltaic areas of East and West Godavari districts [72]. When outbreaks took place in Guntur district of Andhra Pradesh in 1950, severe hopperburn patches covering over 240 ha were distributed among the different fields totalling about 800 ha [72]. The "fulgorid hopper", *Nilaparvata sordescens*, was found in abundance in experimental plots at CRRI in 1953 [25]. The influence of manuring on the incidence of the "fulgorid", *N. lugens*, on rice was observed in Aduthurai, Tamil Nadu in 1954-55 [5]. There were severe outbreaks of BPH in Kerala in 1929 [72], and in the west coastal areas in 1958 and 1960 (B. Thomas, personal communication). Ghose et al. [21] in their book "Rice in India" stated that *N. lugens* had become a serious pest due to intensive cultivation in Andhra Pradesh. It was also mentioned in the same book that the rice fulgorid, *N. sordescens*, was of common occurrence, being commonly found in association with *Nephotettix* species. It has been sporadically a serious pest for some years in Andhra Pradesh, Madras and Orissa, but has caused minor damage in Bihar, Madhya Pradesh, Mysore and Uttar Pradesh.

Light trap data from several AICRIP centers indicated a massive upsurge of the BPH population during the period from 1971 to 1972 [7, 30, 33]. Accordingly, the BPH began to occur in an epidemic scale, particularly in eastern coastal tracts and in southern India, since around 1972.

The first devastating outbreak in Kerala occurred in Alleppey and Trichur districts which represent the rice bowl of this state, during November and December 1973 and January 1974 [4, 16, 22, 35, 37, 38]. In those areas, one or two crops of rice are grown over a large low-lying area by bunding and pumping out the water. The varieties IR8 and Jaya in the post-flowering stage, which were widely grown in the area, were most affected, while a locally bred variety suffered only slightly. The outbreak caused economic damage in about 50,000 ha of paddy fields, of which 8,000 ha were almost completely destroyed [20, 22]. The BPH occurred in epidemic form every cropping season continuously until 1976. The following are the factors which are considered to aggravate the infestation by BPH in Kerala [4, 48].

1). Extensive monoculture and staggered planting of susceptible varieties.

2) Lands surrounded by water-logged areas which provide favorable humid conditions.
3) High seeding rates, up to 112 kg/ha, or transplanting with closer spacing.
4) High levels of nitrogen fertilizer application, 100 to 150 kg N/ha.

In Tamil Nadu, the BPH infestation had long been known by farmers, who called it "Pugayan" in Tamil (S. Chelliah, personal communication). The BPH has caused serious damage once every few years during the recent decades [15]. A devastating outbreak occurred in Kanniyakumari district in 1972 [16]. BPH has also been observed in epidemic form in Thanjavur district in 1975 (B.C. Misra and J.P. Kulshreshtha, personal communication). In addition to these deltaic tracts, a BPH outbreak was reported in Coimbatore district of this state in August 1975 for the first time. The varieties IR20, C4-63, Bhavani and Ratna which were in the post-flowering stage showed hopperburn, resulting in yield losses of 75 to 100% over an area of 1,000 ha [73]. Again from August to September 1976, an outbreak appeared in Coimbatore involving about 3,000 ha planted with the varieties IR20, CO36, and C4-63 in the post-flowering stage, and the nurseries prepared for transplanting in September 1976 also suffered severe hopperburn caused by immigrant macropterous adults (R. Velusamy, personal communication). Outbreaks in this district were thought to be due to the migration of BPH from Kerala.

Severe infestations have devastated the Eastern district of Godavari in Andhra Pradesh since 1974, even during the dry season of 1976 [58]. About 200 ha were destroyed by hopperburn and more than 3,000 ha were severely damaged. In this deltaic tract, two crops of rice are grown as a result of the construction of perennial irrigation canals. The high-yielding varieties RP-14 and Jaya were extensively cultivated there. It was pointed out that indiscriminate and repeated spraying of insecticides beginning with the early crop stage may have been responsible for the unprecedented outbreak noted in the Godavari district [58].

In Karnataka, hopperburn patches were observed near Mandya in May 1975 [11]. Later, from July to October 1975, the BPH appeared to be widespread throughout this state, though in small patches. The varieties attacked were Jaya, IR20, MR301, IET2295, and S701.

During the cropping season of 1973, several thousand hectares of paddy fields were damaged by BPH in Orissa. Infestations were again recorded in the same area for the last two years in 1975 and 1976, but confined to areas of about 500 ha (B.C. Misra and J.P. Kulshreshtha, personal communication).

In addition to the areas mentioned above, sporadic and restricted incidence of BPH was reported in several places in Central and Northern India, for example, in Khopoli in 1971, in the Hooghly district of West Bengal in 1975, and in Bihar in 1975 (B.C. Misra and J.P. Kulshreshtha, personal communication). The BPH has also been reported as a common pest of rice in Himachel Pradesh [12]. In Sri Lanka [18,19], the BPH has been reported previously as a sporadic rice pest in the Southwestern coastal plain. In the late 1960s, the incidence of BPH was found to increase in most rice growing areas. The BPH infestation became serious in Amparai district in the Eastern province since around 1972, and there were very extensive outbreaks in the same area in 1974, when 2,800 ha of paddy field were burned out. In Amparai district, the following cultivation practices are considered as the main factors contributing to the recent outbreaks of BPH:

1) Extensive cultivation of susceptible varieties like BG11-11, BG34-8, H4, and IR8.
2) Staggered planting under perennial water supply with irrigation.
3) Very high planting density due to broadcasting at a heavy seed rate to achieve weed control.
4) Indiscriminate dusting with γ-BHC.

Hopperburn patches were also observed in paddy fields in hilly areas near Kandy in 1976 (T. Fujimura, personal communication).

In Bangladesh, severe BPH outbreaks occurred in April and May on the boro crop and in October on aman crop near Dacca and BRRI in 1976, respectively. Fields planted with IR8 and BR3 varieties were burned in patches [8].

It has been reported that outbreaks of other species of planthoppers and leafhoppers have also occurred in epidemic proportions in certain regions with the advent of high yielding varieties. The white-backed planthopper, *Sogatella furcifera,* gave rise to serious outbreaks on the introduced varieties like TN1, Taichung 65, and IR8-283 in August and September of 1966 and 1967 in Punjab and Mandya Pradesh [54]. Also the green leafhopper, *Nephotettix virescens,* and tungro virus disease transmitted by the leafhopper became widespread in West Bengal, Bihar and Uttar Pradesh during the Kharif season of 1968 and 1969 immediately after the release of Jaya and Padma which have TN1 as parent [29, 45].

On the basis of these findings, it is possible to evaluate changes in pest status of BPH by considering three chronological stages, namely the period preceding 1920, the period extending from 1920 to 1970, and that extending from 1970 until the present time.

1) Period preceding 1920 - The BPH was not regarded as a rice pest in the past when single cropping of native rice varieties was only practiced under rainfed conditions. Usually, inputs were very low without or with minimal application of fertilizers and insecticides. Absence of rice cultivation during the dry season is considered to prevent outbreaks of BPH in paddy fields. The logged areas where the wild rice, *Oryza perennis,* grew throughout the years are the primary habitats of the BPH, with paddy fields being only a temporary habitat.

2) 1920 to 1970 - The sporadic occurrence of the "fulgorid" hopper was noticed in restricted places in Orissa, Andhra Pradesh, Tamil Nadu, and Kerala during this period. It seems likely that the BPH could settle and multiply in the paddy areas where double cropping of rice was common under irrigation. Double cropping gave more chances to carry over the BPH from one cropping season to another. It is certain that irrigation facilities gave the first impetus to the status of BPH in the paddy fields through modification of the cropping pattern.

3) After 1970 - The BPH became very rapidly an important rice pest in India since around 1970. Particularly, the BPH incidence has been severe in the coastal belts in Kerala, Tamil Nadu, Andhra Pradesh, and Orissa states in India, and in the Eastern province of Sri Lanka, where two crops of rice are being grown in a year. Although the BPH has also been found to be endemic in the Central and Northern parts of India, which are mostly single cropping areas, the infestation is rather sporadic and limited to small pockets. These facts again indicate that the double cropping systems under irrigation provide an environment conducive to the perennity of the BPH outbreaks in paddy areas. In addition, as has been repeatedly pointed out by a number of researchers [17, 33, 39], the high yielding varieties program launched in India in 1966 is greatly responsible for recent changes in insect pest status in paddy fields. In 1966 to 1967, a number of exotic high yielding varieties like TN1, Tainan 3, IR8, Taichung 65 were introduced on a large scale in India. Simultaneously, the breeding program to develop indigenous high yielding varieties suitable for India was taken up at AICRIP. As a result, Jaya Padma, and several other varieties were released for general cultivation in 1968 to 1970. TN1 was used as a parent of most of these high yielding varieties, and all of them are highly susceptible to BPH. They also respond to high nitrogen fertilizer application. The recommended dosages of nitrogen for the high yielding varieties are 90 to 185 kg N/ha, while only 40 to 60 kg N/ha for indigenous tall varieties. Such heavy nitrogen fertilizer application is essential for exploiting the full genetic potential of the high yielding varieties. On the other hand, it

also enhances the reproductive potential of BPH. The areas covered by the high yielding varieties increased from 0.89 to 5.5 million hectares during the first four years of the high yielding varieties program. Particularly, coverage with high yielding varieties amounted to 46 to 60% in Tamil Nadu and Kerala during the cropping seasons of 1971 to 1972. Undoubtedly the extensive cultivation of BPH susceptible rice varieties under heavy nitrogen fertilizer application encouraged the upsurge of BPH populations leading to devastating outbreaks. The maximum protection trials conducted under AICRIP in 1972 demonstrated amply that the high yielding varieties could not be grown profitably without adequate insecticidal protection against the insect pests [7,23]. It has already been pointed out that the intensive and indiscriminate usage of insecticides aggravates the pest status of BPH by exerting detrimental effects on the natural enemies of BPH, and often causes rapid resurgence of BPH [18,19,58].

3. Surveillance and control

Following the epidemic of BPH in Kerala, the Directorate of Plant Protection, Quarantine and Storage and Kerala State authorities organized a surveillance program for this pest [10]. A network of surveillance stations has been established to constantly monitor the population buildup, and as soon as a density of 4 to 5 nymphs and adults per hill is reached during the vegetative stage of rice, the farmer is advised to apply insecticides (B. Thomas, personal communication). In Andhra Pradesh, it is generally recommended to monitor the population of BPH at 2 to 3 days intervals commencing from 15 to 20 days up to 60 days after planting; 5 to 10 insects per hill are adopted as a control threshold based on field experiments at AICRIP. An example of the BPH chemical control schedule recommended by AICRIP is as follows [30] :

1) Nursery - Apply Carbofuran 3%, Diazinon 5%, Thimet 10%, Sevidol 8%, or Cytrolane 5% granules at 0.75 kg a.i./ha; or spray thoroughly either with Sevin 50% WP, Nuvacron 100 EC, at 0.4 kg a.i./ha.
2) Early to mid-tillering stages - Foliar application Nuvacron or Dimecron at 0.4 kg a.i./ha; spray nozzle should be directed towards the basal portion of plants.
3) Panicle initiation to booting stage - Preferably apply Carbofuran, Thimet, Diazinon, Sevidol, or Cytrolane granules at 1 kg a.i./ha; or spray with the insecticides recommended previously.
4) Flowering to maturing stages - Spray with insecticides recommended previously or dust with γ-BHC 10% at the basal portion of plants, during afternoon hours.

Among the insecticides so far evaluated, systemic insecticides like Carbofuran [9,52], MIPC [71], and Thiodemeton [4] have been among the most effective chemicals. On the other hand, γ-BHC 10% which had been widely used before being applied as dust was reported to be ineffective in some cases. Also foliar sprays of Chlorfenvinphos, Phenthoate, Mephosfolan and Methyl Parathion were observed to result in severe hopperburn (R. Velusamy, personal communication). The use of insecticides Chlorfenvinphos, Ambithion and Phentoate led to 20 to 50% increases in population over untreated checks. This has been considered to be due to their adverse effects on the predators of BPH. As such it would appear desirable that the integrated way of utilizing insecticides should be given full consideration so as to minimize harmful side-effects of chemicals.

4. Varietal resistance

The varietal resistance of rice to BPH has long been known in India. In 1950, native varieties such as Akkullu, Atragada, Basangi, and Romamani, which were commonly cultivated in the deltaic tracts of Andhra Pradesh, were reported to be very susceptible to the BPH infestation [72]. On the other hand, GEB-24 and Vankisannam were found to resist the infestation even when grown in the midst of susceptible varieties [72]. In 1953 it was also observed at CRRI that the local varieties ADT4, ADT 20, B-76-1, Bemibhog, N136, and PTB 10 showed little infestation, while Chinese varieties planted in the same plots were severely damaged [25]. Differences in performance of BPH depending on varieties have also been reported recently [51,72].

A systematic mass screening program for BPH resistant varieties has been pursued at AICRIP since 1974 [31,32]. Seven to ten days old rice seedlings grown in wooden trays, 50 x 40 x 8 cm, are infested with a large number of 1st to 2nd instar nymphs, at least 5 to 10 nymphs per seedling, in an air conditioned greenhouse. For this purpose, the BPH are successively reared on TN1 plants. Pre-germinated seeds of each entry are grown 3.5 cm apart in 18 cm rows in wooden trays. Each wooden tray accommodates 20 test lines with 15 seedlings, 2 center rows of resistant check, PTB 33 and 4 broader rows of susceptible check, TN1. This layout of test varieties is based on the observation that broader test lines planted at either ends of the trays have increased probabilities of resisting insect attack [34]. When more than 20% of the seedlings of TN1 are killed, seedlings of the test varieties are scored for damage. By this procedure, 1,000 materials can be screened every month and so far about 30,000 varieties and breeding lines have been screened (M.B. Kalode, personal communication).

Of 2,340 local cultivars from different sources in India, 98 were found to be resistant during the course of screening under AICRIP from 1974 to 1976 [31]. Among the germ plasm from the hill tracts of Assam, Meghalaya, and Manipar, 4.3% of the cultivars were found to be resistant to BPH. Ten and 4.7% of cultivars from Pattambi and Coimbatore were resistant, respectively. On the other hand, only a few resistant cultivars were detected in germ plasm from Andhra Pradesh.

At CARI in Sri Lanka, the 985 accessions of local varieties collected from various parts of this country were screened for resistance to BPH, and only 20 cultivars gave over 40% survival when BG11-11, was used while susceptible check, had less than 10% survival [19].

Table 1. Percentages of BPH resistant rice varieties in germ plasms from different sources in India and Sri Lanka (from Kalode and Krishna, 1977; Fernando et al., 1977)

Source	Total no. of varieties tested	Percentage of resistant varieties
India		
Pattambi, Kerala	301	10.0 a/
Combatore, Tamil	514	4.7 a/
Assam	914	4.3 a/
APAU, Andhra Pradesh	44	2.3 a/
AICRIP, Andhra Pradesh	567	0.7 a/
Sri Lanka	985	2.0 b/

a/ 0 - 1.5 based on 0 - 5 scales.
b/ Over 40% survial

From these screenings, it became evident that the resistant cultivars are more densely distributed in the Northeast and South of India than in other parts of the country.

From the breeding program undertaken at CRRI to improve the high yielding varieties by hybridization with resistant local varieties, a promising line, CR94-MR had been selected from the cross (PTB18 x PTB21) x IR8 in 1975 [69]. This line shows good level of resistance or tolerance to BPH as well as to the gall midge, stem borer, *T. incertulas,* and green leafhoppers. In addition to this line, the crosses involving resistant donors such as PTB10, PTB18, PTB21, Leuang 152, Panbira produced progenies resistant to BPH (B.S. Misra, personal communication). A new upland rice variety, Parijat developed from the cross TN1 x TKM 6 is moderately resistant to BPH [44].

Under AICRIP, the following four groups of breeding lines have been found very promising (M.B. Kalode, personal communication). Six RP1045 lines from the cross RP31-49 x Leb Mue Nahng appear to have good BPH resistance and high yielding potential. A parent of these lines, RP31-49-2, was originally bred as a resistant line to the bacterial leaf blight disease, and Leb Mue Nahng is moderately resistant to BPH. Five RP825 lines from the cross Vijaya x PTB21 are resistant not only to the BPH in India but also to all the biotypes at IRRI. Some lines from the cross Sona x Manoharsali and ARC5984 x Pelita are also resistant to BPH.

In Kerala, intensive breeding programs aimed at combining desirable traits of local varieties with the high yield potential of the dwarf indica began in 1964, and three varieties tolerant to BPH, Triveni in 1971 and Jyolthi and Bharathi in 1974 were released for practical cultivation (B. Thomas, personal communication). Triveni was bred from the cross (TN1 x PTB10) x PTB15, and both the Jyolthi and Bharathi originated from the cross PTB10 x IR8. Further improved BPH resistant varieties have been developed since 1974 [26,27]. About 400 lines resistant or tolerant to BPH have been selected from the crosses Bharathi x IR2071-625-3-4, Triveni x IR2061-461, Triveni x Mudgo, and Triveni x IR1539. One of the progenies from the first cross, 1665, was found to be resistant to all the biotypes of BPH at IRRI as well as to the BPH in India.

In Sri Lanka, the breeding program was initiated in 1975. PTB33, Suduru Samba, Heenrath Kunda, and MR1523 are being used as resistant donors [19].

Among these breeding lines, RP825 at AICRIP and a line 1665 at Pattambi are renowned for their general resistance to all the biotypes of BPH, indicating that these lines carry more than one resistant gene.

A unique attempt to isolate BPH resistant mutants through induced mutagenesis [42] has been made at CRRI. About 20,000 plants from the seeds of IET1991 (Sona) treated with ethylmethane sulphonate and nitromethylurea have been screened, and only 15 plants were found to be resistant.

During the course of the breeding work, it was indicated that the varieties ARC6650, ARC7080, ARC1463-B, Lua Ngu, and PTB33 possess dominant genes for BPH resistance, whereas ARC14394, ARC15694, Leb Mue Nahng, MR1523, PTB21 and Unsum have recessive genes [31].

Preliminary studies on the mechanisms at the basis of the varietal resistance of rice to BPH have been initiated at AICRIP [31]. Lower preference for and reduced reproduction on the resistant varieties were observed. A significant difference in honeydew excretions on resistant and susceptible varieties was demonstrated. The existence of a certain relationship between the BPH resistance and silica content could be demonstrated in Sri Lanka [2].

Problems relating to BPH biotypes in India

The distinctive response of BPH to rice varieties, restricted occurrence on resistant rice cultivars in India, and possible interactions between the BPH and resistant rice cultivars in India will be described and discussed in the first part of this chapter. Thereafter, geographic variation of BPH in Asia will be estimated by comparing a certain morphological character of BPH collected in India and Sri Lanka during this trip with that of BPH present in other countries, with special reference to the distinctive varietal response of BPH in those countries.

1. Distinctive varietal response of BPH in India

Immediately after the variety Mudgo was screened out as the first resistant variety to the BPH at IRRI in 1967, it was found that Mudgo was not resistant to BPH in India and Sri Lanka. Although this information did not particularly attract the attention of rice entomologists, it indicated for the first time the occurrence of different biotypes of BPH in the Indian subcontinent. It was again reported that IR26, the first BPH resistant rice variety bred at IRRI, was susceptible at Kerala and Hyderabad in India and also in Sri Lanka in 1973-1974. After that, the report of the first International Rice Brown Planthopper Nursery clearly revealed that most varieties which were resistant to biotypes 1 and 2 at IRRI were also resistant in East and Southeast Asia, but susceptible in India[23,24]. In addition, there were several varieties which showed different reactions depending on the locations. These varieties are useful in describing the geographic variation of BPH in its varietal response. The difference in reactions of selected rice varieties to BPH at 8 locations are summarized in Table 2. From this Table, it is possible to point out that there are three major groups of BPH, which are distributed in East (Japan and Korea), Southeast (Philippines and Indonesia), and South Asia (India). The patterns of varietal responses of BPH in India are apparently distinct from those in other Asian regions. Besides, some cultivars from Assam showed a high level of resistance to BPH at AICRIP, whereas they were very susceptible to all the biotypes of BPH at IRRI[31]. These observations indicate strongly that the BPH existing in the Indian subcontinent is not identical with any of the natural populations found in other Asian countries, nor with any of the biotypes developed so far on particular resistant varieties at IRRI.

2. Gene center for BPH resistance

There appear to be at least two gene centers for the BPH resistance. The Assam area is known to be one of them. At the same time it has been suggested that cultivated rice originated in the mountain ranges embracing Assam, because this is where the richest spectrum of varietal diversity and ecological specialization of cultivated rice has been found[13]. The mosaic of environmental variations, primitive agriculture, and relatively limited human interference is considered to have resulted in and preserved the varietal diversity in this area. The genetic diversity of Assam cultivars has also been demonstrated by means of electrophoretic analyses of esterase isozymes[48]. A number of Assam cultivars have been found resistant not only to the BPH but also to other insect pests and diseases[68].

There is a second center of BPH resistant genes in the South of India including Sri Lanka. In contrast to the Assam area, it is located at the terminal of a route of dispersion of rice cultivation. It has been suggested that the rice cultivation which initiated in the northern hilly tracts spread gradually to the south forming a secondary center of cultivated rice in Jaypore tract in Orissa[66]. The geographic cline in zymogram variation of esterase isozymes supports such a route of diffusion of rice cultivation in the Indian subcontinent[48]. It has even been pointed out that Southern India, particularly Kerala, was a possible center of origin of *O. sativa* because of the presence of wild and cultivated forms of rice under diverse forms[64]. Such diversity in *Oryza* flora and wide variations of rice growing conditions may support the view that mutation and recombination of genes among rice varieties of both the wild and cultivated forms produced new variants showing resistance to BPH. In lands in Kerala where doublecropping is applied, wild rice is a menace to the directly sown rice crops. In fact, the occurrence of natural crossing between wild and cultivated rice exists to a considerable extent and consequently prevalent variabilities are displayed in both

Table 2. Patterns of differential varietal reactions of rice to BPH in different regions of Asia. IRTP, 1976. [1)]

Variety	Japan	Korea	Taiwan	Philippines	Indonesia	Thailand	India
Mudgo, RD 9	R	R	R	R	R	R	S
ARC 10550, 11354	S	S	S	S	S	S	R
ARC 14342	S	S	R	R	R	S	M
ARC 14529, 14766	S	S	S	R	R	R	R
ASD 7	R	R	S	R	R	R	S
Murungakayan 3	M	M	S	R	R	R	S
IR1154-243-1	R	R	S	R	R	M	S
Triveni	S	S	R	S	R	R	S
TR26	S	S	M	R	R	R	S
Leb Mue Nahng	S	S	S	S	S	M	M

1) R - resistant; M - intermediate; S - susceptible.

forms[47]. Also certain characters of wild rice such as drought resistance have successfully been incorporated into the cultivated rice. Some of the endemic and generally dominant characters like bold grain and red pericarp may partially be the result of introgressive hybridization.

3. Evolution of the BPH resistant rice varieties

It is possible that the BPH resistant cultivars appeared during or after domestication of *Oryza perennis*, the progenitor of *O. sativa*, because *O. perennis* is generally susceptible to BPH. However, there is no positive evidence that the biotic pressure of BPH played a significant role in the evolution of BPH resistant cultivars in the Assam area, where the BPH has never been a prevalent rice pest. It seems more logical that certain physiological modifications during the genetic diversification process brought about the BPH resistance to selected cultivars.

The same assumption seems possible in the case of BPH resistant native varieties in Southern India. Although BPH outbreaks have recently occurred in epidemic form in these areas, it is considered that such close interaction between the BPH and cultivated rice has been established only recently since a few decades. On the other hand, the BPH resistant native varieties existed much longer before the BPH represented a significant rice pest. The resistant genes for the BPH biotypes at IRRI are rather restrictively found among the ADS, HR, MTU, PTB, and SLO strains. These correspond to the period extending from 1920 to 1950 in Andhra Pradesh, Tamil Nadu, and Kerala states. So, it is clear that the resistant varieties had already been present in these states before 1920.

It seems, therefore, reasonable to assume that the biotic pressure of BPH did not play any significant role in the evolutionary process of resistant varieties of cultivated rice in both the Assam area and Southern India.

4. Origin of BPH biotypes

Natural occurrence of breakdown in the host resistance to biotypes of BPH which had been observed in the Philippines, Indonesia, and Solomon Islands after the introduction of the resistant variety IR26 indicates that BPH populations are fairly flexible in their response to rice varieties. This may also lead to the assumption that the distinctive ability of BPH to infest resistant rice varieties as seen in India, could develop under cultivation of resistant rice varieties. As already mentioned, the distinctive varietal responses of BPH in India had been noticed early in 1967. However, it is doubtful whether the situation was suitable for the development of a breakdown in the host resistance to biotypes in India at that time. The biotype 2 in the Philippines, Indonesia, and Solomon Islands readily appeared when the BPH populations giving rise to severe outbreaks were subjected to extreme selection pressure as a result of the extensive cultivation of the resistant variety IR26. This evidence suggested that the perennial occurrence of BPH in paddy areas and the extensive mono-culture of a particular resistant variety are the necessary conditions the development of new biotypes.

In the areas of Godavari and Krishna in Andhra Pradesh, where irrigation is supplied all the year round, SLO 13 and MTU 1 were the most popular varieties under cultivation during the 1960s; these were resistant to biotypes 1 and 2. A similar condition might also have existed in Telengana region of Andhra Pradesh and Kerala, where BPH resistant HR, RDR, and PTB varieties were commonly cultivated in the past before the introduction of modern high yielding varieties (see Table 3). In such places particular biotypes could develop. However, the resistant cultivars were not always predominant, and susceptible varieties were also widely planted as well, even in Southern India. For example, most of CO and ADT strains in Tamil Nadu, and AKP strains in the Northern region of Andhra Pradesh were susceptible.

Table 3. BPH susceptibility of improved local rice varieties recommended in each state of India before the introduction of modern high yielding varieties. [1)]

State	Resistant	Intermediate	Susceptible	Unknown
Jammu and Kashmir			CH 1039	Baber, Budigi, CH971, CH 1007, Lutanzan
Punjab			Basmati 370, Thona 349	Dundar 43, Ramjanain 100
Rajastan			NP 130	HR 1
Uttar Pradesh	CH 4	CH 10	N 10B, N 22, T 21, T 136	Judha
Assam			Latisail	AS 3, Prasadbhog, SC 94-47
Bihar	BR 6		BR 8	BR 34, BR 46
West Bengal	Patnai 23		Ashkata, Bhasamanik	Kalimpong 1
Madhya Pradesh			Triple Cross, R-2 Nungi, Cross 116	Nausahi, R4
Orissa	T 90, T 1242	BAM 6, FR 43B	T 141	SR 26B
Andhra Pradesh	HR 19, MTU 15, SLO 13		SLO 16, SLO 17	IJ 52, PLA 1
Karnakata			B 1399, CO 25, CO 29	B 1370, S 661, S 222
Tamil Nadu			ADT 3, C 025, C 029 CO 30, GEB 24	ADT 28
Kerala	PTB 2, PTB 31		PTB 10, PTB 32	UR 19

1) Recommended rice varieties are referred from Ramiah (1966)[61]. The BPH susceptibility of each variety is based on the IRRI data obtained with BPH biotype 1.

In this connection, it is worth noting that the BPH populations at IRRI which gave rise to outbreaks under continuous cultivation of resistant and susceptible varieties at varying proportions since 1967 have still retained their original nature. This may indicate that the mixed planting of resistant and susceptible varieties prevents or at least inhibits the development and prevalence of particular biotypes of BPH. Likewise it is considered that the new biotypes of BPH did not so readily occur under the mixed cultivation of various resistant and susceptible varieties in India as in the case of the biotype 2 on IR26 in Southeast Asia. Besides, the BPH populations at CRRI, AICRIP, Pattambi and Pantnagar show similar varietal responses in spite of a relatively restricted distribution of resistant varieties (Table 4).

This information seems to make it difficult to support the hypothesis that the present day BPH populations in India evolved under similar circumstances as the biotype 2 on IR26 in the Philippines, Indonesia, and Solomon Islands. Other theoretical approaches are necessary to understand the distinct population characteristics of BPH in India from the viewpoint of the long term evolutionary process of Indica rice in India and of the BPH populations.

The following consideration may provide a clue to further investigations of the BPH biotypes in India. In Godavari area in Andhra Pradesh, for example, the improved local rice varieties MTU and SLO strains were commonly cultivated during the 1930s to 1960s. They are the varieties selected from predominant native varieties in that area like Akkullur, Basangi, and Konamani at Maruteru and Samalkot Agricultural Research Stations from 1925 to the 1950s. The original native varieties, the improved indigenous varieties selected from each of the native varieties, and their reactions to the three biotypes of BPH at IRRI are grouped in Table 5. From this table, it can be seen that there are wide variations in the reaction to each BPH biotype among the sister strains selected from the same group of local varieties. This seems to indicate that the original native varieties showed very wide genetic variations in their susceptibility to the BPH. It could be said that such nature of rice varieties is somewhat similar to the so-called multilines, consisting of individual plants carrying different kinds of resistant genes. Until the recent breeding work was taken up, the BPH population had long been exposed to such native varieties with heterogeneous characters. It is conceivable that there was no strong unidirectional selection pressure operating on the BPH populations to replace one type by another, because the population density was far below the carrying capacity of the host plants during that period. Under such circumstances, particular biotypes could not develop, but it seems possible that the diversity of genetic characters of the original BPH populations living on the perennial wild rice could be well maintained under a stable equilibrium between the genetic variations of rice and BPH. This may be the reason why the BPH populations in India have the ability to feed on broad ranges of rice varieties. In order to verify this hypothesis it is important to understand the genetic status of the BPH populations on the wild rice or from areas where native rice varieties are cultivated. Certain variations in the varietal reaction of rice to the BPH at different locations in India may be due to random gene-frequency fluctuation in the populations.

5. Estimate of geographic variation of BPH in Asia

In the previous sections of this chapter, the distinct varietal responses of BPH populations in India have been described. However, the possibility that such differential nature of BPH populations could be induced in the presence of resistant rice cultivars has not been fully supported. An attempt was made to discuss this problem from the point of view that such differentiation could be attributed to geographic variation of this tropicopolitan species irrespective of recently cultivated rice varieties.

It has been demonstrated by the author that there are significant differences in the frequency

Table 4. **Difference in varietal reactions of rice to BPH at different locations in India and to the three biotypes at IRRI (from IRTP, 1976, 1977; Pathak and Lal, 1976)[1]**

Variety	India				IRRI		
	CRRI	AICRIP	Pattambi	Pantnagar	1	2	3
PTB 33	R	R	R	M	R	R	R
PTB 21	M	M	M	S	R	R	R
PTB 19	R	M	R	S	R	R	R
CO 9	M	R	R	S	R	S	R
Gangala	M	S	S	S	R	R	R
Murngakayan 101b	S	S	S	M	R	R	S
RP 9-6	S	S	M	S	R	S	R
ARC 6650	R	R	R	M	R	M	S
ARC 10550, 11354	–	R	–	–	S	S	S
ARC 15570A, 15831, 15872	–	M	–	–	S	S	S

1) R - resistant; M - intermediate S - susceptible

Table 5. **The BPH susceptibility of improved local rice varieties in Godavari district, Andhra Pradesh.** 1)

Variety	IRRI Accession No.	Biotype 2) 1	2	3
		Akkullu strains		
MTU 1	00650	7	3	5
MTU 1	04903	7	-	-
MTU 2	00654	9	9	9
SLO 6	16325	-	-	-
SLO 13	00659	1	1	7
SLO 13	06013	1	-	-
SLO 14	00641	5	3	7
PLA 4	00685	9	7	9
RDR 4	04905	7	-	-
RDR 4	06076	9	-	-
		Atragada strains		
MTU 6	00671	7	3	-
MTU 12	00656	9	-	7
MTU 14	00635	3	3	7
MTU 14	05837	5	-	-
BCP 3	00646	5	3	9
BCP 3	05835	3	-	-
		Basangi strains		
MTU 3	00232	9	9	9
MTU 3	04904	7	-	9
MTU 3	06332	5	-	-
MTU 4	00726	9	9	9
MTU 4	06404	9	-	-
MTU 20	00670	1	9	5
MTU 20	06376	7	-	-
SLO 7	26836	-	-	-
SLO 8	00668	7	9	9
SLO 9	00666	5	3	5
SLO 9	06431	7	0	0
		Konamani strains		
MTU 11	00664	7	5	7
MTU 11	06024	5	-	-
SLO 1	00556	-	1	9
SLO 1	06036	9	-	-
SLO 2	00678	5	3	7
SLO 3	26860	-	-	-
SLO 4	26861	-	-	-
SLO 15	00062	9	9	9
SLO 15	06185	7	-	-
GEB 24 3)	05909	9	-	-
GEB 24 3)	06115	2	-	-

		Krishnakatukulu strains		
MTU 5	00634	5	5	9
MTU 5	05892	9	-	-
MTU 5	07808	5	-	-
MTU 10	00645	9	9	9
MTU 10	04807	7	-	-
		Nallaralu, Garikasannavari strains		
MTU 9	06290	7	-	-
MTU 9	07919	1	9	1
MTU 15	00233	1	9	3

Note: Possible synonyms of local varieties [21, 60, 62]

Akkullu: Akkulur, Bontaakkullu, Bonthaakkullu, Gavaakkullu, Pottiakkullu, Punasaakkullu, Sannaakkullu.

Atragada: Bontratragada, Pettaatragada, Pedhaatragada, Pottiatragada.

Basangi: Bontabasangi, Bonthabasangi, Peddabasangi, Pottibasangi, Punasabasangi, Sannabasangi, Rasangi, Gortirasangi, Guttirasangi.

Konamani: Peddakonamani, Punasakonamani.

Krishnakatukulu: Bonthakrishnakatukulu, Sannakrishnakatukulu.

1) Based on 0 to 9 scales at IRRI.
2) Biotypes at IRRI.
3) Mutant in Konamani.

distributions of the hind basitarsus spines among the three biotypes of BPH at IRRI. In order to estimate the geographic variation, the average number of spines and the frequency distribution of insects with different number of spines were compared among the BPH specimens collected at 3 locations in India as well as those collected in 6 other Asian countries (Fig. 3). The three biotypes developed at IRRI were also examined.

The average number of spines on the hind basi-tarsus of BPH collected from different Asian countries and the three biotypes at IRRI are shown together in Fig. 3 with their 95% confidential ranges. Generally the BPH populations in India and Sri Lanka have more spines than those in Southeast and East Asia. The average number of spines is also significantly larger than that of any of the biotypes at IRRI. The comparative frequency of polygons for the spines shows different features among the three groups of BPH as shown in Fig. 4. Again it was disclosed that the BPH in South Asia, India and Sri Lanka was different not only from the BPH in Southeast and East Asia, but also from all the biotypes at IRRI.

These morphological variations seem to indicate that the BPH populations in the Indian subcontinent represent an isolated population different from those of other parts of Asia. Detailed studies on the biotypes of BPH in India are in progress as regards this hypothetical viewpoint.

Concluding remarks

1. Since around 1970, BPH outbreaks have been observed in epidemic form in the eastern coastal tracts and southern parts or India and Sri Lanka. The causes of population upsurges have been extensively discussed by a number of researchers mainly from the viewpoint of habitat modification due to the change of rice varieties and cultural practices. However, critical studies on the population ecology of this species are not completely documented. Particularly the information about the alternation of host plants or habitat during the off-cropping season, dispersion from epidemic coastal areas to inland hilly tracts, and the factors keeping the population very low on the rice during the vegetative growing stage would be important for the understanding of the population dynamics of BPH and eventually for considering management tactics for this insect pest. In this connection, the establishment of monitoring techniques is essential. If the density of immigrants could be successfully monitored by appropriate methods (yellow pan trap, high net trap, or sticky board trap), it could also be possible to forecast the outbreaks of BPH. The light trap data will not be so useful for those purposes. It should be emphasized that the ideal integrated control of BPH could be attained only through detailed ecological studies of this insect, and it would thus become possible to avoid the aggravation of pest status of BPH due to indiscriminate application of pesticides.

2. Studies on varietal resistance of rice to BPH and the breeding of rice varieties resistant to this insect should be done with full understanding of population characters of the existing BPH populations, so as to avoid the rapid breakdown of the resistance of the released varieties and the prevalence of virulent biotypes. At present, the genetic characters of the BPH in India remain quite obscure in spite of strong indications that the BPH in India has distinct infectivity to the rice plants which are resistant to BPH in the rest of tropical Asia. It is necessary to verify whether the BPH in India is a particular biotype (physiological phenotype) or mixed population of several biotypes and to test the gene for gene relationship between the resistant genes in rice varieties and the countergenes in the BPH biotypes. Also information survey on the genetic nature of old rice varieties which were commonly cultivated in India, and studies on the population characteristics of the BPH on the rice plants of wild or very native forms in the areas isolated from modern rice cultivation areas will provide valuable data for the biotypes studies. Changes of genetic char-

acters of field populations of BPH may take place very rapidly under some circumstances, as in the case of biotype 2 on IR26, or much more slowly, or not at all, in others. The evolution of BPH biotypes is an exceedingly complex process determined by the interaction of genetic and biological factors of the BPH population, and the cultural situations of resistant rice varieties. The genetic factors involve the initial frequency and dominance of the genes that confer the breakdown of varietal resistance of rice. The population size, generation turn-over, migration (dilution effect by immigrants), reproductive advantages or disadvantages in each BPH genotype are the main biological factors. The intensity and mode of selection pressure by cultivation of resistant varieties are the operational factors under human control. There are now several proposed strategies to control and stabilize the prevalence of the BPH by means of genetic manipulation of rice under cultivation in the form of sequential, mosaic, or mixed cultivation of monogenic, or polygenic resistant varieties, or multilines. These function as selection pressures with different levels and different modes of action on the BPH populations. It is important to evaluate the effect of each type of cultural-operational factors on the genetic status of the BPH populations as well as to evaluate its effects on controlling the population density of BPH, in order to prevent the development of more virulent biotypes. It is possible to simulate the effects of operational factors on the gene frequency and population trends of the BPH population under various circumstances by the use of computers. For this purpose, detailed studies on the population ecology of BPH are necessary to design a basic model for the study of population dynamics of this species in the fields, as well as for the genetic and biological studies of the known BPH biotypes.

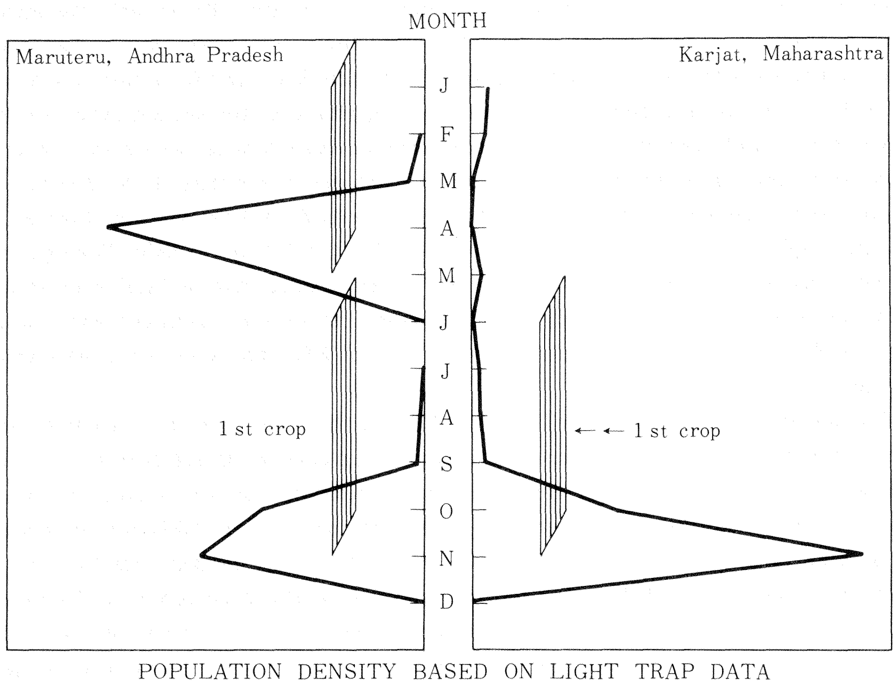

Fig. 1. Population fluctuation of BPH in single and double cropping areas (from AICRIP, 1971, 1972)

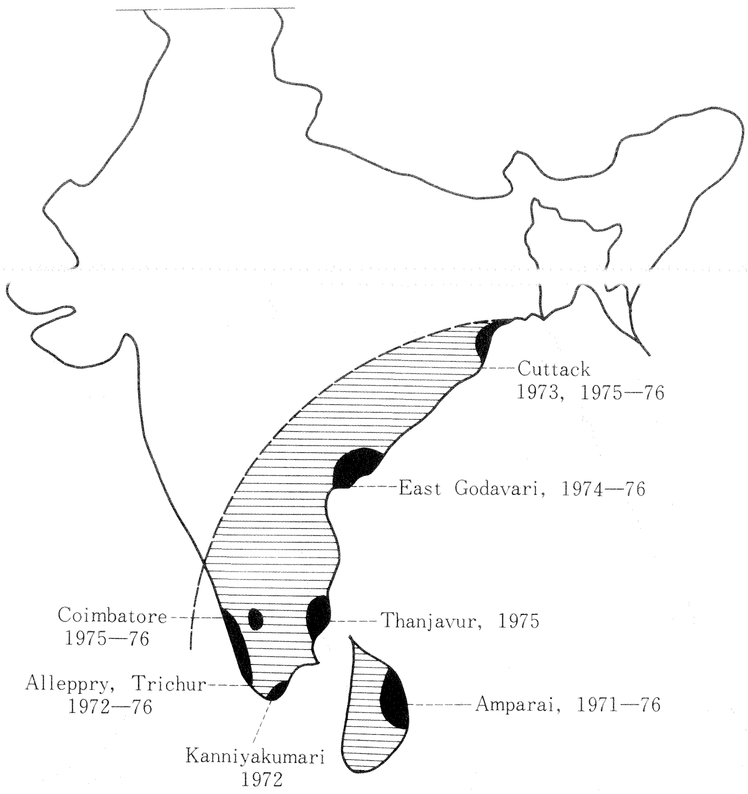

Fig. 2. BPH epidemic areas in India and Sri Lanka.

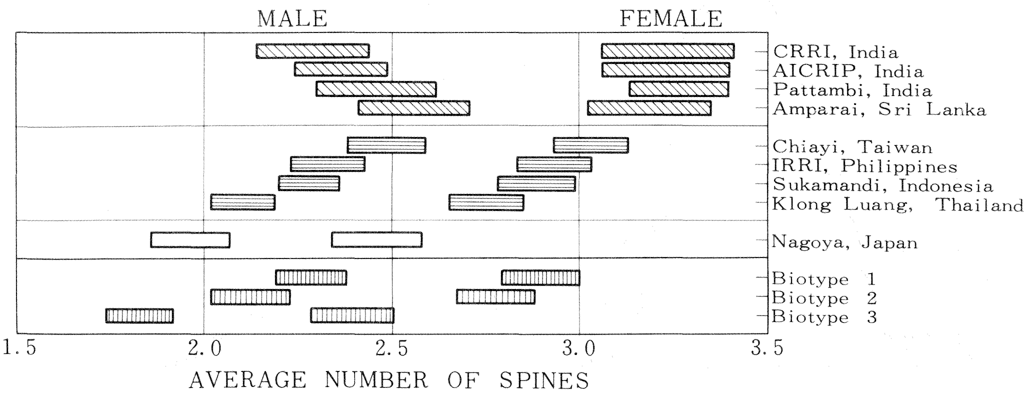

Fig. 3. Confidence range (95%) for the average spine number on the hind basi-tarsus of BPH collected in various regions in Asia and the three biotypes at IRRI.

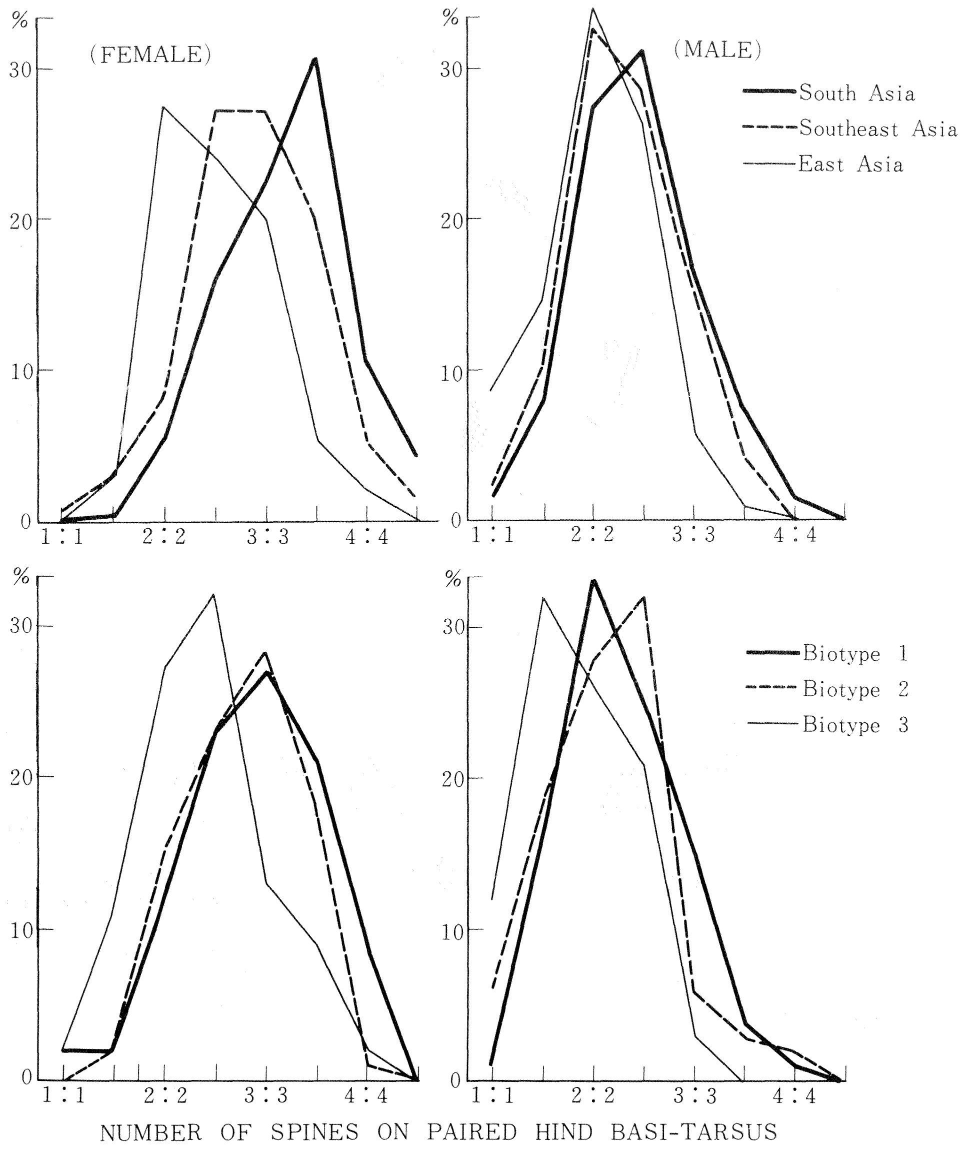

Fig. 4. Comparative frequency of distribution of polygons in relation to the number of basitarsus spines in different groups of BPH populations.

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