

**“GENETIC ANALYSIS OF RESISTANCE TO BROWN
PLANTHOPPER, *Nilaparvata lugens* (Stål) IN SOME
SELECTED RICE VARIETIES”**

Ph.D. (Ag.) THESIS

By

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INDIRA GANDHI AGRICULTURAL UNIVERSITY
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**“GENETIC ANALYSIS OF RESISTANCE TO BROWN
PLANTHOPPER, *Nilaparvata lugens* (Stål) IN SOME
SELECTED RICE VARIETIES”**

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॥ गुकं ब्रम्हा गुकं विष्णू
गुकं देवो महेश्वराः
गुकं साक्षात् परब्रम्हः
तस्मै श्री गुरुवे नमः ॥

VITAE

The author was born on December, 18 1975 in Nanded (M.S.). He received his elementary education from Govt. School Parbhani; Secondary education from Yogeshwari Nutan Vidyalaya, Ambejogai and passed HSSC in 1993.

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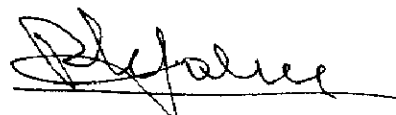
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In 1999, he was admitted Indira Gandhi Agricultural University pursue his Ph.D. studies in Plant Breeding and Genetics minor in Entomology.

CERTIFICATE -I

This is to certify that the thesis entitled "**Genetic Analysis of Resistance to Brown Planthopper, *Nilaparvata lugens* (Stål) in Some Selected Rice Varieties**" submitted in the partial fulfilment of the requirements for the degree of "**Doctor of Philosophy in Agriculture (Plant Breeding and Genetics)**" of the Indira Gandhi Agricultural University, Raipur (C.G.), is a record of the bonafide research work carried out by **Shri Umate Sunil Marotirao** under my guidance and supervision. The Student's Advisory Committee and the Director of Instructions have approved the subject of the thesis.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published / published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.



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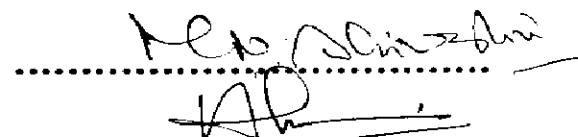
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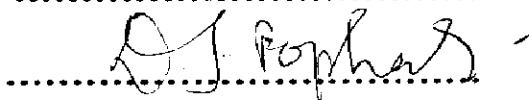
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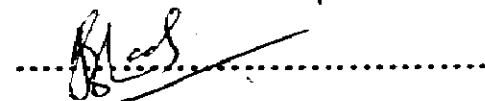
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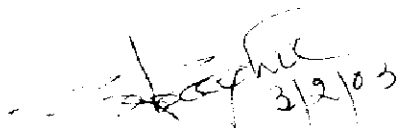


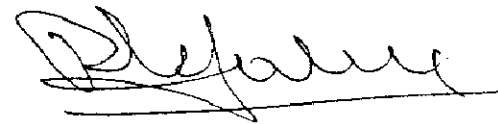
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CERTIFICATE - II

This is to certify that the thesis entitled "**Genetic Analysis of Resistance to Brown Planthopper, *Nilaparvata lugens* (Stål) in Some Selected Rice Varieties**" submitted by **Shri Umate Sunil Marotirao** to the Indira Gandhi Agricultural University, Raipur, in the partial fulfilment of the requirements for the degree of **Ph. D. (Ag.)** in the Department of **Plant Breeding and Genetics** has been approved by the Student's Advisory Committee after oral examination in collaboration with the external examiner.


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INTRODUCTION

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) belongs to the genus *Oryza* of the tribe *Oryzae* of the family *Graminae*. The 22 recognised species, including the Asian and African cultivated rices consisting the genus are broadly grouped into four complexes viz., *Sativa*, *Officinalis*, *Ridley* and *Meyeriana*. Cultivated rice is a secondarily balanced polyploid derived from an ancestral *graminaceous* species with a basic chromosome number of 5. During the evolutionary process two of the chromosomes were duplicated resulting in two types of plants viz., $2n = 14$ and $2n = 10$. The amphidiploid of the cross between the two variants ($2n = 12$) resulted in the cultivated and its wild ancestors with $2n = 24$ chromosomes.

There is hardly any crop plant that grows under as diverse agroclimatic conditions as rice does. Geographical distribution of rice growing areas extends from 50° North in Central Czechoslovakia on the Equator to 35° South in Australia. The growing conditions vary from below sea level in Kuttanad region of Kerala (India) to as high as 2000 m in the Himalayas, extreme water regimes ranging from highly drought prone uplands (< 50 mm rainfall) to flood prone / deepwater lowlands (2-3 m depth), temperature in the range of 33° C in West Pakistan to 17° C in North Japan and soil reaction from acidic ($pH < 4$) to alkaline/saline soils ($pH > 11$ and $Ec > 4.0$). Given its adaptation to such a wide range of growing conditions, defining of typical "Rice Climate" would not be easy

Rice is the world's most important food crop. It is the staple food of more than two-third of world's population and sole food for an estimated 1.3 billion people of world (Coffman and Herrera, 1980). It is now grown on about 153 million hectares in more than 100 countries. About 92 % of all rice is grown and consumed in Asia (Khush and Coffman, 1977). Great varietal diversity in rice is found in Asia and is due to the force of natural selection and the continent's diverse cultural, geographical and climatic conditions.

In India, rice was grown in 44.5 million hectares with an annual production of 85.5 million tonnes and an average productivity of 1.9 t/ha in 2000-2001 (Singh, 2002). Rice area and production increased from 38.8 million ha. and 20.6 million tonnes in 1950-51 to maximum of 45 million ha. and 89.5 million tonnes 1999-2000, respectively. The productivity has also increased from 0.67 tonnes in 1950-51 to 2.0 t/ha in 1999-2000. The rice production was reduced by 4 million tonnes in 2000-2001 due to drought in some parts of the rice growing states.

In Chhattisgarh State, the area under rice was 38.07 lakh ha. with a production of 47 lakh metric tonnes (Anonymous, 2000) in 1999-2000. It is very surprising that although Chhattisgarh State is known as "rice bowl", productivity of rice is only 1.3-1.4 t/ha which is half of the national average productivity.

More than 100 species of insects are pests of rice but only about 20 of them are of major economic significance (Pathak, 1977; Pathak and Khush, 1979). The brown planthopper, *Nilaparvata lugens* (Stål) was one of the most serious insect pests of rice in Japan many years ago (Kisimoto, 1960) but was a

minor pest in most of the tropical rice growing areas. At present the insect is a serious threat to rice production throughout Asia.

The brown planthopper is a small (2.0 – 3.5 mm in body length), brownish, sucking insect, belonging to the Sub-order *Homoptera*, Series *Auchenorrhyncha*, Super Family *Fulgoridae*, and Family *Delphacidae*. Members of genus *Nilaparvata* are characterized by several lateral spines on the hind basitarsus (Okada, 1977). The adult shows density dependent wing dimorphism with macropterous and brachypterous forms (Hasegawa, 1955). Macropterous adults have ability to migrate over long distance. The brown planthopper is endemic to the tropical region, but its habitat can temporarily expand as far north as Japan and Korea every summer through long distance massive migrations from the tropics (Kisimoto, 1971). The brown planthopper is a monophagous insect restricted to cultivated rice and its allied wild forms such as *Oryza perennis* and *Oryza spontanea* (Kisimoto, 1965). Thus, the seasonal occurrence and relative abundance of the brown planthopper depend largely upon cropping patterns and intensification of rice cultivation.

Brown planthopper, *Nilaparvata lugens* (Stål) has assumed importance in recent times because of different biotype development (Table 1.1). Its extensive damage to rice crop in India was first observed in Kerala during 1973 (Nalini Kumari and Mammen, 1975). Subsequently reports were also received from main rice growing tracts of India viz., Andhra Pradesh, Bihar, Orissa, Punjab, Tamil Nadu and Uttar Pradesh (Kulshreshta, 1974).

Table: 1.1 Biotypes of brown planthopper and major resistance donors for each biotype

Biotype	Areas where predominant	Major resistant donors	Suscep. check	Genes for resist.	Mode of Inheritance	Varia - bility	Mech. of resist.
I	East and South East Asia	Mudgo, ASD 7, IR 26, IR 29	TN 1	<i>Bph 1</i>	Monogenic dominant or recessive Rarely di or trigenic complementary	High	Antibi osis
II	Philippines and Indonesia	ASD 7, Ptb 18	Mudgo, IR 26, IR 29	<i>bph 2</i>			
III	?	Rathu Heenati, IR 26, IR 29	ASD 7	<i>Bph 3</i>			
IV	?	Babawee	TN 1	<i>bph 4</i>			
Unnamed	South India and Sri Lanka	Ptb 19, Ptb 20, ARC 6650		----			

In Chhattisgarh, this pest is recently assuming a status of major pest. In 1976, its severe outbreak in the region reduced the yields by 34.4 per cent (Gangrade *et al.*, 1978). A general increase trend in the insect population has been observed during the past few years. Although, it is difficult to pinpoint the cause of the increase in pest population, it has been attributed to the reduced genetic variability of short – statured and high tillering varieties of rice, heavy use of nitrogenous fertilizers, the practice of continuous cropping and staggered planting. The brown planthopper causes direct damage to rice plant by sucking the plant sap. In addition to the feeding damage it also transmits grassy stunt (Rivera *et al.*, 1966), ragged stunt (Ling *et al.*, 1978); and wilted stunt virus diseases of rice (Chen *et al.*, 1978). Heavy damage caused by brown planthopper in the field can be identified by the development of circular patches in the field.

which is termed as “Hopper burn” (Plate No. 1). Despite various chemical control measures, varietal resistance in rice has provided a highly practical approach for controlling insect problem. Concentrated efforts for utilizing insect resistance in rice improvement programmes began about two decades ago at IRRI. However, systematic research in establishing basis of resistance against the pests started only within the last decade. To date, 12 resistance genes have been discovered against the brown planthopper. (Table 1.2)

Table: 1.2 Gene sources for resistance to brown planthopper, *Nilaparvata lugens* (Stål) stress

Resistance Gene	Donor Sources	References
<i>Bph 1</i>	Mudgo, Balamvee, Co.10, Co.20, MTU 15, TKM 6	Athwal <i>et al.</i> , (1971)
<i>bph 2</i>	ASD 7, Ptb 18, Ptb 33, Madayal, Dikwee 328, Malkora	Athwal <i>et al.</i> , (1971)
<i>Bph 3</i>	Ptb 21, Ptb 33, Rathu Heenati, Gangal, Muthumanikam, Homamawee, Ptb 19	Martinez and Khush (1974)
<i>bph 4</i>	Babawee, Senawee, Hotel Samba, Sulai, Thirissa, Lexham Samba	Martinez and Khush (1974)
<i>bph 5</i>	ARC 10550	Martinez and Khush (1974)
<i>Bph 6</i>	Swarnalata	Sidhu and Khush (1978)
<i>Bph 7</i>	T 12	Sidhu and Khush (1978)
<i>Bph 8</i>	China Saba, Co.5 Thailand	Sidhu and Khush (1978)
<i>Bph 9</i>	Pokkali, Kaharamna, Balanmawee	Khush <i>et al.</i> , (1986)
<i>Bph 10 (t)</i>	-----	Jenna <i>et al.</i> , (1992)
<i>Bph 11(t)</i>	-----	Liu Guo Qing <i>et al.</i> , (2000)
<i>Bph 12(t)</i>	-----	
<i>IBph 1</i>	-----	Martinez and Khush (1974)

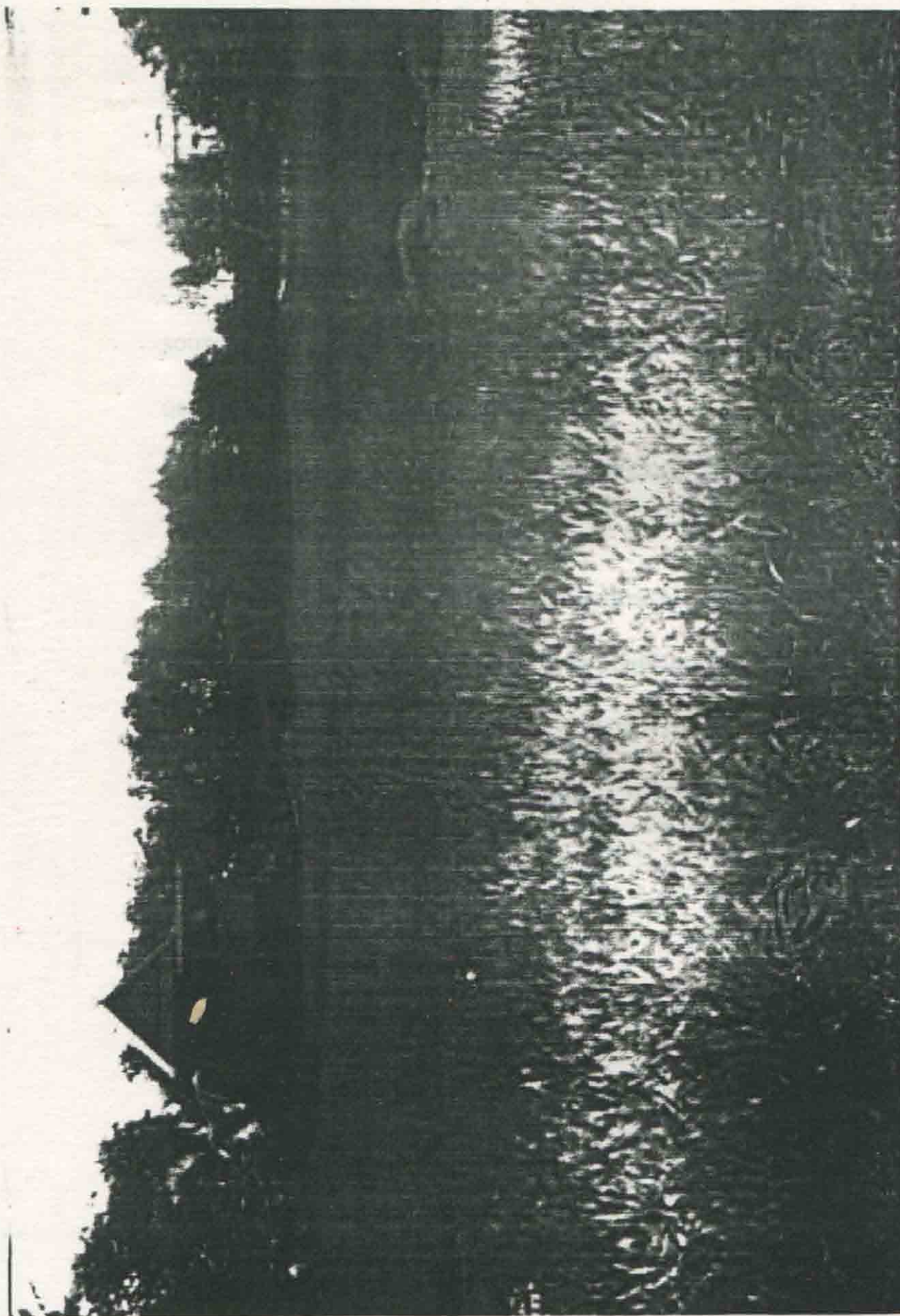


Plate No.1. Damage caused by *Nilaparvata lugens* (Stal) in the field

The use of resistant varieties is a logical and the most effective method of combating insect pests. Because resistance to pest is inherited in plants, it involves no extra cost to the farmers, nor does it impair the quality of the environment. The only limitation to the success of resistant varieties is the potential threat of new biotype development (Glass, 1975). This problem can be overcome by identifying new genetic sources of resistance in the world collection of germplasm and utilizing them in developing new varieties.

Considering the importance of resistant varieties and of diverse resistance sources for controlling brown planthopper, the present investigation was undertaken with following objectives:

1. To determine the mode of inheritance of resistance to brown planthopper in 11 resistant rice varieties.
2. To determine the allelic relationships of resistance genes with known genes for resistance to brown planthopper.
3. To determine the allelic relationships of resistance conferring genes present in some of the donors.

REVIEW OF LITERATURE

CHAPTER II

RIVEIW OF LITERATURE

2.1 Taxonomy:

Super Family	:	<i>Fulgoroidae</i>
<i>Sogetella furcifera</i> (Horvath)	:	Rice White Brown Planthopper
<i>Nilaparvata lugens</i> (Stål)	:	Rice Brown Planthopper.

Commonly known as leaf hoppers (*Cicadellids*) and plant hoppers (*Fulgorids*), these pests were sporadic in most rice tracts (Israel *et al.*, 1959), becoming serious in certain years. Recently, their role as factors limiting rice production has been recognised owing to their increase in numbers and transmitting virus diseases of paddy in epiphytotic form.

2.2 Symptoms, nature of damage and habits:

The planthoppers of the genus *Nilaparvata* feed on the basal parts of the plants and the entire plants dry up. Often, sooty moulds and sclerotia are found at the sites of their damage (Misra and Israel, 1968; Verma and Lal, 1975). The adults of planthoppers are usually seen on the foliage, but the nymphs remain at the lower regions of the plants, where they feed, grow and moult, with the result that their cast skins are seen attached to stems. The bunchy appearance, narrow and short erect leaves, which are pale green or grassy green, with rusty spots, are symptoms associated with the grassy stunt disease transmitted by *Nilaparvata lugens*. The adult of brown planthopper is uniformly light or dark brown with chestnut eyes and measures 3 – 4 mm. Nymphs are white when newly hatched and later on turn brown. Eggs of *Nilaparvata sp.* are laid in batches of 4-6 and

single female lays about 530 eggs. Adult *fulgorids* live for 30 – 56 days (Misra and Israel, 1968.)

When the infestation is light, there is a loss of general vigour and a reduction in tillering, height, productive tillers and increase in sterility or number of unfilled grains. Severe infestation causes the condition called ‘hopper burn’ and can destroy the crop completely in the affected area. This is caused by the nymphs and adults sucking the sap from the basal plant and plugging the vascular bundles with their stylet sheaths causing drying of tillers.

2.3 Life Cycle:

The life history of brown planthopper was studied in Japan by Harukawa (1951), Suenaga and Nakatsuka (1958), Suenaga (1963), Mochida (1964), Kisimoto (1965), Hirao (1972) in Fiji by Hinckley (1963), in Philippines by Bae and Pathak (1970) and in Taiwan by Tao (1965).

2.3.1 Eggs:

Eggs are usually laid in masses in lower part of the rice plant, mainly in the leaf sheath and occasionally in leaf blades. The size of the egg masses and ovipositional sites depend upon the growth stage of rice plant. When the adult population is high, eggs are also found in the upper parts of the plants (Mochida, 1977). The number of eggs per mass has been recorded to be 2 – 3 in Japan (Suenaga, 1963; Nasu, 1967) and 4 – 10 in the Philippines (Bae and Pathak, 1970). The eggs are cylindrical; their interior ends are attached to each other and their caps are flat (Nasu, 1967). Newly laid eggs are whitish in colour and become darker and develop two distinct eye spots (Bae, 1966). The incubation period is 7 – 11 days (Plate No. 3) (Mochida and Okada, 1979).

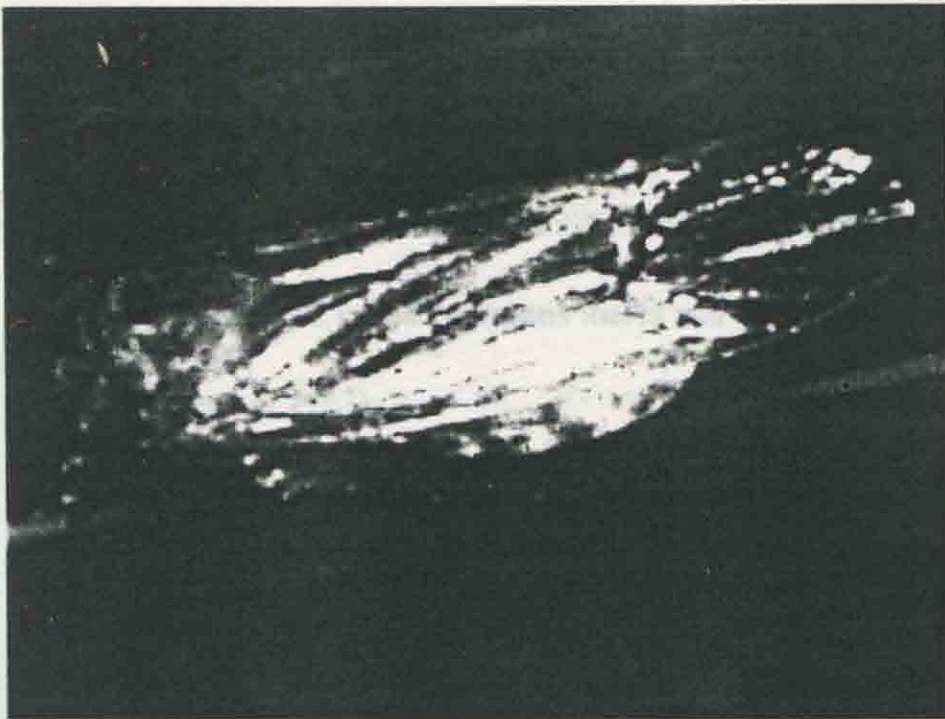


Plate No. 2 Winged adult of *Nilaparvata lugens* (Stal)

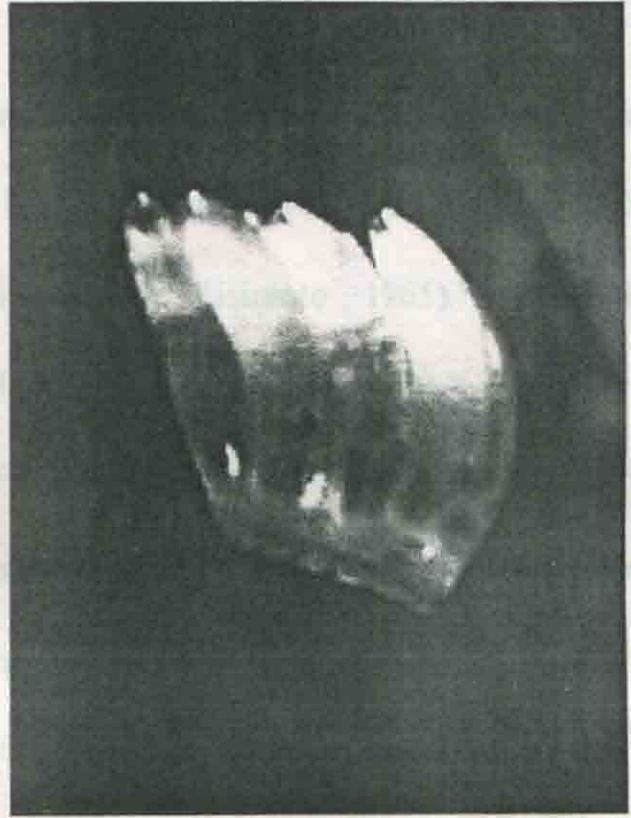


Plate No. 3 Egg mass of *Nilaparvata lugens* (Stal)

2.3.2 Nymphs:

There are five nymphal instars which are distinguished by the size of the body and shape of the meso and metanotum (Mochida, 1977). The nymphal development period lasts 10 – 15 days.

2.3.3 Adults:

There are two wing morphs: macropterous and brachypterous. The macropterous have normal front and hind wings and are capable of flight, while non – flying brachypterous have reduced wings (Kisimoto, 1965). The body is dark brown in colour. Males are smaller in size. (Plate No. 2)

2.4 Life History and Behaviour:

The brown planthopper is widely adapted to varying environmental conditions in the tropical and temperate regions. The adult remains active between 10⁰ C to 32⁰ C (Suenaga, 1963). The preoviposition period varies from 7 to 11 days. The incubation period is shorter at low temperature (about 20⁰ C), while longer at high temperature (about 30⁰ C) (Hirao, 1972). At a temperature of 33⁰ C, nymphal mortality increased and body size was reduced (Suenaga, 1963; Bae and Pathak, 1970). The temperature to which the nymphs are exposed is known to affect the adult female longevity and oviposition (Mochida, 1964). Adult longevity for macropterous males is 20 – 37 days and for females, 25 – 31 days (Mochida and Okada, 1979). The temperature range for normal behaviour is 9⁰ C to 30⁰ C in macropterous males and 10⁰ C to 32⁰ C in macropterous females (Suenaga, 1963).

The brown plant hopper (*Nilaparvata lugens*) first appeared in August – September, with peak numbers in October and November and again in February

and March (Misra and Israel, 1968). The specific reasons attributed to the outbreaks of brown planthopper in recent years were the successive rice cropping, large scale cultivation of susceptible rice varieties, resulting in a dense growth of the crop and favorable microclimate, ineffective aerial spraying of pesticides, the excessive use of parathion, BHC, etc. in recent years eliminating the natural predators (spiders) and parasites.

2.5 Alternate hosts:

Zaheruddeen and Prakasa Rao (1985) studied the brown planthopper oviposition on 52 common rice weeds, 17 wild rices and 21 crop plants in no-choice tests. Oviposition was inside the leaf sheath tissue on following weeds: *Brachiaria ramosa*, *B. distachya*, *Dichanthium caricosum*, *Digitaria ciliaris*, *Echinochloa colona*, *E. stagnina*, *Eragrostis gangetica*, *E. pilosa*, *E. tenella*, *Leersia hexandra*, *L. perrieri*, *Leptochloa panacea*, *Panicum repens*, *Paspalum scrobiculatum*, *P. flavidum*, *Pennisetum pedicellatum*, *Rottboellia exaltata* and *Setaria pallide-fusca*; wild rices *Oryza alta*, *O. australiensis*, *O. barthii*, *O. eichingeri*, *O. collina*, *O. glaberrimum*, *O. grandiglumis*, *O. meyeriana* ssp. *Grandulata*, *O. latifolia*, *O. minuta*, *O. nivara*, *O. officinalis*, *O. perennis*, *O. punctata*, *O. ridleyi* and *O. rufipogon*; and on crop plants viz., wheat, barley, oats, finger millet, foxtail millet, kodo millet, proso millet, little millet and Japanese millet. Oviposition was inside the stem tissue just below the flower head in the weeds viz., *Cyperus compressus*, *C. difformis*, *C. distans*, *C. iria*, *C. rotundus* and *C. tenuispica*. The insect oviposited inside the tender stem tissue of weeds *Bergia ammannioides*, *Commelina benghalensis*, *Heliotropium indicum*, *Hydrolea zeylanica*, *Ipomoea reptans*, *Ludwigia perennis* and *Sphenoclea zeylanica*; and on

crop plants viz., maize, sorghum, pearl millet, peanut, mung bean, black gram, sun hemp, and jute. The insect laid naked egg clusters on the leaf lamina of weeds *Eleusine indica* and *Dactyloctenium aegyptium*.

2.6 Resistance mechanism:

Pura (1974) reported that the mechanism of resistance to *Nilaparvata lugens* involved non-preference and antibiosis.

Anonymous (1976) reported that preliminary tests have shown that resistant varieties contain greater amount of phenols than susceptible varieties.

Reddy and Urs (1988) evaluated the effect of six plant extracts on brown planthopper oviposition. Seed extract of *Annona squamosa*, *Sapindus trifoliatus*, *Acacia concinna*, *Gynandropsis*, *Pentaphylla*, *Hydrocarpus alpine* and *Ocimum gratissimum* significantly reduced oviposition.

Aquino and Heinrichs (1979) studied the effect of a resurgence causing insecticide cypermethrin on different rice varieties resistant to *Nilaparvata lugens*. Study revealed that brown planthopper populations remain low on varieties that are highly resistant to the prevailing biotypes in spite of being sprayed with a resurgence causing insecticide.

Chatterjee and Dutta (1979) reported that *Neoscona theisi* (Walckenaer), *Lycosa* sp., *Oxyopes* sp., *Marpissa decorata*, *Tikader* and *Theridion* sp. were observed to prey on brown planthopper (*Nilaparvata lugens*).

Yoshihara and Sogawa (1979) found that soluble silicic acid, common in rice plants, strongly inhibited sucking by the brown planthopper. The absence of significant differences in contents of soluble silicic acid and insoluble silica among susceptible and resistant varieties indicated that silicic compounds do not

influence brown planthopper resistance. The silicic acid possibly influences phloem localization by the insect, thus preventing an erroneous sap intake from parenchymal tissues.

Yoshihara *et al.*, (1979) reported that the resistance to brown planthopper in certain rice varieties was mainly governed by chemicals in the phloem tissues that inhibited sucking. In the susceptible varieties, the average concentration of oxalic acid was 0.18 mg/g fresh tissue. In 5 groups of resistant varieties, it was 0.34-0.45 mg/g fresh tissue. Similarly, the total organic acids in susceptible varieties contained significantly less oxalic acid (4.4%) than those in resistant varieties (7.6-11.0%), suggesting that oxalic acid was a chemical factor governing brown planthopper resistance in rice.

Krishnaiah *et al.*, (1982) studied different insecticides for toxicity to brown planthopper eggs and nymphs and reported that Fenvelverate, Cypermethrin and Carbosufan as 0.05% sprays exhibited quick knock down effects and persistent toxicity. Carbaryl, Phosphomidon, Phosplone, Quinolphos, Endosulfan, Chloropyrifos, Isofenphos, Fenthion, Thiometon, Fenitrothion, Dimethoate and Phenothoate were relatively less toxic. BPMC exhibited downward translocation but the effect did not persist beyond 5 days. Carbosulfan, MIPC, BPMC, Knockbal, Carbaryl, Isofenphos, Phosalone and Monocrotophos had the highest ovicidal activity.

Rawat and Diwakar (1982) conducted surveys to identify the parasites and predators of the different rice pests and reported *Cyrtorhinus lividipennis* as a common parasite of *Nilaparvata lugens* with high prevalence during 1975-80.

Balasubramanian and Mariappan (1983) reported that 6 species of fungi were isolated from brown planthopper and out of these 6 species, *Fusarium oxysporium* caused 67.3% and 40% mortality of brown planthopper nymphs and adults, and *Cephalosporium lecanii* killed 75.9 and 52.7% brown planthopper nymphs and adults. Spraying fungal suspension containing conidia and mycelia caused higher death rates than spraying the culture filtrate or treating the insects with fungal mass.

Mochida and Basilio (1983) studied the insecticide resistance of brown planthopper to Chloropyrifos + BPMC; acephate the study revealed that long term use of insecticide has undoubtedly hastened the development of insecticide resistant brown planthopper populations.

Upadhyay and Diwakar (1983) conducted surveys during 1980 in Chattisgarh to identify the natural enemies of brown planthopper. The *Tytthus parviceps* (Reuter) with scattered incidence and *Cyrtorhinus lividipennis* (Reuter) has a widespread incidence on the brown planthopper in the paddy fields.

Aguda and Listsinger (1984) studied the different isolates of *B. bassiana*, an entomogeneous fungus to determine their virulence on plant hoppers. The study revealed that isolates E, RS149 and 101481-5 were the most virulent against all insect species. RS149 and 101481-5 had higher virulence to brown planthopper. Brown planthopper was most susceptible to *B. bassiana*. Isolates RS413, 102381-8 C and E had higher virulence to brown planthopper and green leafhopper than whitebacked planthopper.

Sujatha *et al.*, (1987) studied the relationship between chemical composition and resistance of 11 rice varieties to the delphacid *Nilaparvata*

lugens in the field. The results suggested that the phenols silica, phosphorus, potassium, calcium, sulphur and iron contents were positively correlated with resistance, while nitrogen, zinc and manganese contents were negatively correlated with resistance.

Fabellar and Mochida (1988) reported that when LD₅₀ values were compared among locations, prevailing temperature could cause inconsistent results. Brown planthopper and green leafhopper were susceptible to most of the insecticides at higher temperatures and to pyrethroids at lower temperatures. For brown planthopper, all insecticides except Cypermethrin and Deltamethrin had lower LD₅₀ values at 33°C than at 18°C.

Macatula *et al.*, (1988) studied the activity of Buprofezin, a slow acting insecticide at three different concentrations against brown planthopper, whitebacked planthopper and green leafhopper. They observed that hopper populations were less with increasing rates of Buprofezin. Buprofezin at 12.5 g ai/ha was as good as higher rates against whitebacked planthopper, green leafhopper and brown planthopper nymphs and comparable to BPMC and Cartap at 750 and 1000 g ai/ha, respectively.

Zhang and Wu (1992) using improved bulk screening method tested 4816 rice varieties for resistance to *Nilaparvata lugens*. They reported that most of the exotic varieties showed antibiosis, while most of the indigenous varieties were tolerant.

Telan *et al.*, (1994) tested several extracts from plant species for use in controlling brown plant hopper. Some of the botanicals treatments were significantly more effective than others, but none were nearly as good as effective

as Endosulfan. *Azadirachta indica*, *Anonas reticulate* and *Tinosphora rumphii* appeared to have repellent effect on brown planthopper.

Liu Guang *et al.*, (1999) reported that resistance levels of some test varieties at seedling stage were closely correlated to those at tillering stage. At the same time, the resistance levels in certain other varieties increased with increasing plant age. Also resistance levels using honeydew excretion criteria were similar for seedling and tillering stages.

Nanda *et al.*, (2000) conducted the studies to determine the biochemical basis of *Nilaparvata lugens* resistance. The total free amino acid content at 30 DAS was significantly higher in TN1 (8.12%) compared with the other cultivars (ranging from 5.27 to 7.37%). At 45 DAS, the total amino acid content was reduced in all cultivars, but in general amino acid content of TN1 was higher than that of the resistant cultivars (excluding ARC 6650 and Utri Rajpan). The total starch content was highest in TN1 at 30 DAS (8.12%) compared with the resistant cultivars (5.32 – 7.17%). At 45 DAS, the total starch content was reduced in all cultivars, but in general, starch content of TN1 was higher than that of resistant cultivars (excluding ARC 6650 and UR and Babawee). At 30 DAS, the total sugar content was 2.05% in TN1, similar to that of ARC 6650 (2.17%) but higher than the remaining cultivars (0.92 – 1.85%).

2.7 Biotype Variation:

The brown planthopper (BPH) is one of the most serious rice pests in tropical and temperate Asia. Since Athwal *et al.*, (1971) identified *Bph1* and *bph2* genes in Mudgo and ASD 7, respectively, twelve resistance genes have been reported to date. Four biotypes of brown planthopper are known. Biotype 1 is

widely distributed in East and Southeast Asia; biotype 2 originated in Philippines after wide scale cultivation of varieties with *Bph1* gene and biotype 3 was produced in laboratories in both Japan and the Philippines. Biotype 4 is found only in South Asia.

Variation in the biotype of *Nilaparvata lugens* (Stål) from one region to another and from one country to another, particularly in Asia, had long been recognized and reported by several workers (Ida Nyomar, 1978; Saxena and Mujer, 1985; Sogawa, 1993).

Reeshan Feuer (1976) reported the presence of brown plant hopper biotype 2 in Southern Luzan in September 1975 and in 1976 insecticide and rice variety recommendations were changed to meet the new menace of biotype 2 of brown planthopper.

Sogawa (1978) observed no significant differences among biotypes in dimensions of body portion; but significant variations were found among biotypes in frequency distribution of number of spines on the hind basitarsus of adult insects. The average spine number in biotype 1 and 2 and in the biotype developed on the variety Babawee did not differ significantly from that of natural populations at IRRI; it ranged from 2.76 to 2.93 for the female and 2.12 to 2.33 for the male.

Verma *et al.*, (1979) reported the existence of an additional biotype (the Pantnagar population) that differed from four other biotypes. Varieties those were resistant to the biotype in Southern India and Srilanka and those, which are resistant to other three biotypes, succumb to this new biotype.

Anonymous (1982) the reaction of differential varieties to feeding of brown planthopper in tests throughout Asia indicated that the South Asian brown planthopper population is distinct from that of Oceania, East Asia and South East Asia. Within India, there may be slight differences in Hyderabad, Coimbatore and Pantnagar populations. Four distinct brown planthopper biotypes can be recognized in Asia from the reaction of differential varieties. The wild types populations in East and South East Asia and Oceania belong to biotype 1. Biotype 2 became predominant in Solomon Islands, Indonesia, Philippines and Vietnam after IR 26 was widely grown. Biotype 4 occurs in India, Bangladesh and Sri Lanka.

Cytological studies of the meiotic chromosomes of brown planthopper biotype 1 and 2 maintained as stock cultures at IRRI for several years by Saxena (1983) revealed that meiosis I and II were reductional and equational for all components of species' genome. He observed similar phenomenon for biotype 3.

Veronica and Kalode (1983) studied the reactions of five rice varieties with different resistance genes and high degree of resistance for 3 different populations of *Nilaparvata lugens*. The results indicated that, although the populations were not sufficiently distinct from each other, to be considered different biotypes, they were distinct from the Philippine biotypes.

Velusamy *et al.*, (1984) studied the differential response of rice varieties to the brown planthopper in International Screening tests. They observed that the brown planthopper population on the Indian subcontinent was not the same as natural populations in other Asian countries. The *Bph 1* and *bph 2* genes did not confer resistance to Tamil Nadu and Pondicherry brown planthopper populations.

however, *Bph 3* and *bph 4* genes conferred resistance to brown planthopper populations occurring in Philippines and in South India. Differential varietal reactions indicated that the brown planthopper population in Tamil Nadu and Pondicherry is different from South Asian population.

Goh *et al.*, (1993) conducted morphological investigations of the abdominal lateral lobes in tarsi of legs in males and females of three Korean biotypes of *Nilaparvata lugens* they reported that the tarsi of legs in males and females of three biotypes varied from one another. The presence of a distinct cut on the lateral lobes in brachypterous females' distinguished biotype 2 from biotype 1 and 3. The highest frequency of inserted unguitactor plates in fore and mid tarsal segments was exhibited by biotype 2 in both sexes of each morph.

Nguyen Long Chau *et al.*, (1993) collected seven brown planthopper field populations from different agroecological areas of the Mekong Delta in 1991 to determine the changes in brown planthopper biotype. All the brown planthopper populations studied killed TN1. Mudgo (*Bph1*) was susceptible to all 7 brown planthopper populations. The resistance of ASD 7 (*bph2*) broken down, indicating that brown planthopper biotype 2 had developed a new distinct biotype that was not similar to biotype 3 from IRRI. Rathu Heenati (*Bph3*) and Ptb 33 (digenic gene) were still resistant to all populations. Babawee (*bph4*) was moderately susceptible to all brown planthopper populations. This suggested that a new biotype the 'Mekong Delta brown planthopper' population had developed.

Lu Zhong Xian *et al.*, (1999) compared differences in tolerance of three *Nilaparvata lugens* biotypes to high temperature, starvation, soaking in water and insecticide treatment under laboratory conditions. The LT_{50} of biotype 1 nymphs

at 35° C was significantly shorter than that of biotype 2 and the greatest longevity of female adults experiencing starvation among the 3 biotypes tested was found in biotype 1 at 22° C and 26° C. Biotype 1 was the most susceptible to methmidophos, while biotype 2 recorded significantly greater tolerance to buprofezin than biotype 1 or 3. These results implied that the differences in tolerance to starvation and insecticides could be important factors influencing the observed shift in *Nilaparvata lugens* biotypes.

Lu Zhong Xian *et al.*, (1999) observed the feeding, oviposition selectivity and probing behaviour of different biotypes of *Nilaparvata lugens* on TN1, IR 26, and ASD 7. There were no significant differences among the selectivities of biotype 3. Adults preferred TN1, while there were no significant differences among the selectivities of biotypes 1 and 2. No obvious differences among the probing frequencies of biotype 2 on the three varieties were recorded. Biotype 1 and 3 adults preferred to oviposit on IR 26. Under no choice feeding conditions, the probing frequencies of biotype 1 on TN1 decreased significantly and that of biotype 3 on ASD 7 increased significantly.

Tanaka (1999) studied the virulence of brown planthopper (*Nilaparvata lugens*) that immigrated into Japan in 1992, 1995 and 1996 on four *indica* rice cultivars. The results obtained were that, the 1995 and 1996 populations of *Nilaparvata lugens* had higher proportions of virulent females on the *Bph 1* carrying rice varieties, 54-79% on IR 26, 39-66% on Mudgo and 95% on Saikai 190, than the 1991 and 1992 populations. However, all the tested populations had still low proportions of virulent females on the rice varieties carrying *bph2*, *Bph3* or *bph4*, especially those carrying *Bph3* or *bph4*. These results showed that

virulence to *Bph1* in the *Nilaparvata lugens* populations immigrating into Japan has become stronger after 1988-1990 in which change of the virulence was first found and suggested that resistance of *Bph1* had broken down for these *Nilaparvata lugens* populations.

Wang Gui Rong *et al.*, (1999) studied the shift of virulence in rice brown planthopper in the field and laboratory. They observed that field populations differing in virulence can shift to ASD 7 type populations after rearing for 4 generations on resistant rice cultivar ASD 7 type population gradually weakened during rearing on susceptible rice cultivar TN1. After rearing on TN1 for 7 generations, the ASD 7 type population degenerated into a TN1 type population. It is concluded that virulence of rice brown planthopper is variable and exterior factor inducing the virulence shift is the resistant or susceptible character of the host plant.

2.8 Sources of resistance:

Pura (1974) reported that out of 421 varieties tested for nymph infestation at one leaf stage, 35 varieties showed some resistance.

Kudagamage (1976) evaluated 500 indigenous and foreign introductions for the resistance to *Nilaparvata lugens*. Of these Ptb 33, ARC 6650, Suduru Samba, MR 1523 and Sudu Heenati exhibited resistance against pest.

ARC 6650 was also reported to be highly resistant to Hyderabad biotype and moderately resistant to a local Pantnagar one. (Anonymus, 1977)

Bak *et al.*, (1977) reported that Milyang 30 derived from a complex cross involving Tong-il (strain 1) IR 946-52-1-3, IR 1317-392-1-2, IR 1539-290-2-2 and Milyang 21 had shown good resistance to *Nilaparvata lugens*.

Kalode *et al.*, (1977) reported 14 new donors possessing the multiple resistances to *Nilaparvata lugens*, *Sogetella furcifera*, and *Pachydiplosis oryzae*.

Sai Krishna *et al.*, (1977) reported that when 890 cultivars from NE India were screened for resistance to *Nilaparvata lugens*, 69 were resistant or moderately resistant.

Suartini (1977) reported that out of 2334 varieties and lines tested, 41 were highly resistant and 237 resistant to *Nilaparvata lugens*.

Weerapat *et al.*, (1977) concluded that by planting 50 % of an area with a resistant variety, the damage resulting from attack is reduced to levels lower than those expected on the basis of the different ratios of the varieties used.

Balasubramanian *et al.*, (1978) reported that out of 844 bulk progenies, 804 single plant selections, 988 germplasm entries and 62 varieties which were screened, 22 varieties including 'Nira' exhibited resistance to *Nilaparvata lugens*.

Heinrichs *et al.*, (1978) screened 128 varieties for resistance against *Nilaparvata lugens* and reported that photosensitive varieties Babawee, Rathu Heenati, Ptb 33, Cr 157-380-292, CR 157-392-4 and IET 5122 were resistant to all the 3 biotypes.

Kalode *et al.*, (1978) reported that the variety Ptb 33 was least preferred by nymphs of *Nilaparvata lugens* than TN 1.

Lin and Cai (1978) observed that Taixhong (Taichung) 229 was resistant to *Pyricuralia oryzae* and *Nilaparvata lugens* and moderately resistant to *Xanthomonas oryzae*, *Corticium sasakii* and *Stenertarsonemus spinki*.

Ida Nyomar Oka (1978) reported that resistance to the grassy stunt and *Nilaparvata lugens* occurred in IR 26, IR 28, IR 30, IR 32 and IR 34. Of the total

3740 varieties and lines tested, 19 showed some resistance against both virus and brown planthopper.

Venugopala Reddy and Kalode (1981) evaluated a total of 1070 varieties to identify better sources of brown planthopper resistance. In mass screening replicated test, resistance (less than 1.5 score on a 0-5 scale) was shown by only 18 varieties, ARC 500, ARC 5754, ARC 5757, ARC 5764, ARC 5780, ARC 5858, ARC 5917, ARC 5973, ARC 5981, ARC 5988, ARC 12864, ARC 13854, ARC 13966, ARC 14394, ARC 13507, ARC 14539, ARC 14766A and ARC 14703. Moderate resistance (1.6 to 3.0) was observed in 73 varieties. ARC 5780, ARC 5973 and ARC 12864 exhibited less damage and were comparable to the resistant check Ptb33.

Chang (1982) reported that Tainung 68 from the cross Nankai-7u // 4 /// Nankai - 7u 77 // Tainan 5² / ASD 7 was resistant against brown planthopper. The resistance to brown planthopper was inherited from ASD 7, which expressed at late growing stages.

Heinrichs *et al.*, (1982) evaluated rice varieties IR 5 to IR 54 for resistance to brown hoppers, leaf folder and case worm in greenhouse; and yellow stem borer in the screen house and whorl maggot in the field. All IR varieties except IR 22 showed resistance to at least one pest.

Heinrichs *et al.*, (1985) observed that IR 26, IR 28, IR 29, IR 30, IR 32, IR 34, IR 36, IR 40, IR 42, IR 44, IR 45, IR 46, IR 48, IR 50, IR 52, IR 54, IR 56, IR 58, IR 60 and IR 62 possessed resistance to either biotype 1, 2 or 3 of brown planthopper.

Ikeda (1985) analyzed 11 cultivars by crossing with genotypes carrying known resistance genes and assessing response to biotype 2 and 3. Balamwee (70-518), Kaharamana and Pokkali had a new unknown dominant gene while Col.5 – Thiland, Col.11 – Thiland and Chinsala, had a new unknown recessive gene. Hondarawala 378 had *Bph3*, while Balamwee (70-164), Ptb7, Ptb12 and Ptb20 had both dominant and recessive genes.

Velusamy and Chelliah (1985) reported that Mudgo and ASD 7 rices carrying *Bph1* and *bph2* resistance genes were susceptible to brown planthopper populations from Tamil Nadu and Pondichery, while Rathu Heenati (*Bph3*) and Babawee (*bph4*) were resistant. ARC 6650, ARC 10550, IET 5741, IET 6315, T7, ASD 11, Sinna Sivappu and V.P. Samba showed consistently resistant reactions to brown planthopper populations from Tamil Nadu and Pondichery.

Babu and Rajendran (1986) reported that Co: 19 and Ptb 33 were resistant to both *Nilaparvata lugens* and *Cnaphalacrocis medinalis*.

Rao (1986) evaluated 1250 lines out of nearly 20,000 rice germplasm accessions available at CRRI, and reported that 59 cultivars and 15 cultures were resistant. Among them are 31 AC 20, ARC 1, MNP 1, JBS and 6 from other sources, of these 12 (ARC 14529, ARC 14760, ARC14766, ARC14766 A, ARC 10550, ARC 14342, AC 3376, AC 3747, Ptb 19, Ptb 21, Ptb 33, T 1415, T 1426) had been reported resistant in different parts of India.

Murthy *et al.*, (1988) screened 200 traditional cultivars of Madhya Pradesh for resistance against brown planthopper twelve entries were scored as resistant (3.0-3.7), 18 were moderately resistant (4.3-5.0), 28 susceptible and 7 was scored as highly susceptible (7.7-9.0).

Nguyen Van Luat *et al.*, (1988) reported that OM 91, derived from the cross 900 x IR 747 has shown high resistance to biotype 2 of the development of the delphacid *Nilaparvata lugens* on two subspecies of rice *Oryza sativa* subspp. *Japonica* and *indica* and observed that the rate of food intake, growth and development of nymphs were greatest on japonica rice as compared to *indica* rice.

Park and Song (1988) studied the biology of delphacid *Nilaparvata lugens* in terms of feeding and oviposition preferences. The study revealed that fecundity and oviposition preferences of 3 biotypes on Dongjinbyeo (no resistance genes) were greater than for cultivars with resistant genes. Preference of biotype 2 for Cheongcheongbyeo (*Bph1* gene) and biotype 3 for Milyang 63 (*bph2* gene) was relatively high but lower than those for Dongjinbyeo. Egg and nymphal periods of all 3 biotypes were shorter on Milyang 23. Egg hatchability emergence ratio and growth index of all 3 biotypes were highest on Milyang 62.

Velusamy (1988) screened 128 wild rices (*Oryza* spp.) for resistance to *Nilaparvata lugens* in green house tests, and observed to be 83 were resistant. Two wild rice species *Oryza officinalis* and *Oryza punctata* reduced the percentage hatch of *Nilaparvata lugens* eggs.

Sahu and Shrivastava (1989) screened some 400 rice accessions against *Nilaparvata lugens* using standard seed box screening technique and reported 7 accessions were resistant to the pest.

Velusamy and Saxena (1989) reported that Rathu Heenati, Babawee, ARC 10550, Swamalata & Ptb 33 were resistant to brown planthopper in screening trials while IR 747-B 2-6 & ASD 7 were susceptible. Fecundity and

egg viability were higher on TN 1, IR 747 B2-6 and ASD 7 than on Rathu Heenati, Babawee, ARC 10550, Swarnalata and Ptb 33.

Hasan and Kamal (1992) tested the nature of resistance in the rice varieties Hotel Samba, Kuruhondarawala, ARC 10550 and Swarnalata (each containing different resistant genes). The study revealed that feeding by *Nilaparvata lugens* was lower on Swarnalata as compared to other rice varieties.

Remabai and Nair (1992) carried out a tiller screening test for brown planthopper, *Nilaparvata lugens* on 42 rice cultivars comprising TN 1 (susceptible check), Ptb 33 (resistant check) and 40 cultivars of diverse origins of known resistance.

Zheng and Chou (1992) evaluated 4261 and 3477 germplasm accessions respectively for resistance to brown planthopper and whitebacked planthopper during 1986-91 and reported that 181, 236, and 18 accessions showed resistance to brown planthopper, whitebacked planthopper and both pests respectively.

Pophaly and Rana (1993) evaluated 21 IR varieties for resistance to *Nilaparvata lugens*. Of these IR 62 and IR 64 were resistant; IR 34, IR 36 and IR 56 were moderately resistant and the 16 cultivars were susceptible.

Reddy and Misra (1996) evaluated 30 rice cultivars for resistance to *Nilaparvata lugens*, of these Culture 1, IR 28 and IR 8 were least susceptible but were significantly less resistant than the resistant check Ptb 33.

Based on the 5 greenhouse tests conducted under controlled conditions and field evaluation at Mandya, 10 cultures (MTU 1046, MTU 1036, MTU 1037, MTU 1042, MTU 1047, BPT 102-50-1 and BPT 2157) could be identified with less than 5 damage score or less than 10% plant damage in 5 or 6 tests

Anonymous (1999). One of the culture MTU 1046 recorded low damage in all the six tests, including the greenhouse tests at Pantnagar, where only three entries had low rating of 5 or less score.

Suresh *et al.*, (1999) conducted a study in Madurai (TN), India to evaluate the resistance of several rice hybrids to *Nilaparvata lugens* with high yielding susceptible rice cultivars, viz., IR 50, Kannagi, TKM 9, Co 33, ASD 16, ADT 36 and Co 37 and the resistant cultivars TNAU-BPHR 831283, TNAU 831521, W 1263, ARC 6650 and ARC 10550. Five hybrids were moderately resistant; 11 were susceptible and 6 were highly susceptible to *Nilaparvata lugens*.

Tao Lin Yang *et al.*, (1999) evaluated 34 resistant and 2 susceptible varieties for brown planthopper resistance. The results indicated that 15, 3 and 16 rice varieties had long, middle and short resistance respectively at seedling stage. seventeen varieties expressed the same durable resistance levels in adult stage as in seedling stage.

Anonymous (2000) based on 4 greenhouse tests, four promising (KAU 1661, KAU 9412-8, MTU 1037 and MTU 1044) cultures could be identified. From 6 field tests, 8 promising (KAU 9410-8-1, BPT 107-18-1, BPT 112-6-2, BPT 2157, CR 589-46-2-2-1, MTU 1037, MTU 1044, TTB 281-31) cultures were detected. Two of the cultures under retesting viz., MTU 1037 and MTU 1044 performed well in both field and greenhouse tests.

Anonymous (2000) conducted screening trails involving a total of 712 breeding lines and 441 germplasm accessions were evaluated against 12 major insect pests at 42 locations across the country. Entries promising against brown planthopper were MTU 1036, MTU 1037, MTU 1042, MTU 1044, MTU 1048,

BPT 2157, BPT 112-6-2, BPT 107-18-1 PLA 10934, CR 589 46-2-2-1 from planthopper screening trial : INRC Nos. 202, 3524, 3526, 3753, 3779, 3905, 3994, 5358, 5718, 17402, 17465, 17466, 17503, 15504, 17508, 17518, 17548 from MRST; IET Nos. 15339, 15495, 15581, 15948, 15949, 16075, 16144, 16270, 16274, 16307, 16441, 16519, 16533, 16536, 16439, 16724, 16783, 16804, 16805, 16806, 16810, 16834 from NSN 1; IET Nos. 15420, 16970, 16987, 16994, 17000, 17005, 17108, 17133, 17154, 17183, 11354A from NSN 2.

Anonymous (2000) out of the 65 local trial entries from 16 crosses, 13 cultures were found to have multiple resistance to blast, brown planthopper, whitebacked planthopper, Gall midge biotypes 1,2,5 and other sporadic pests in multi-location testing also displayed high yield potential. Among the cultures reported to be resistant to brown planthopper are RP 3463-G61, RP 3463-G63, RP 3463-G64, RP 4112-G79, RP 2547-D34, RP 4392-G58, RP 3917-E49384 and RP 3513-EMRST 49586.

2.9 Genetics of resistance:

Studies on genetics of resistance to brown planthopper were started at IRRI in 1968 and also carried out independently in Japan, Korea and Taiwan. Mode of inheritance and allelic relationships of the newly identified genes were studied. Two genes for resistance were identified by Athwal *et al.*, (1971). The dominant gene of Mudgo was designated *Bph1* and recessive gene of ASD 7 was designated *bph2*.

Chen and Chang (1971) in Taiwan, investigated inheritance in Mudgo and concluded that resistance was controlled by a single dominant gene and three varieties, IR 9-60, Kaosen Yu 12 and H 5, were found to have *bph2*.

Fernando *et al.*, (1971) in Sri Lanka investigated the genetics of resistance against brown planthopper in Ptb 33 and found that it had a single dominant gene for brown planthopper resistance.

Athwal *et al.*, (1971) found that Mudgo, Co 22 and MTU 15 each possessed a single dominant gene for resistance to brown planthopper. The single gene for resistance in these varieties was allelic to *Bph1*. The resistance gene of ASD 7 behaved as recessive gene and was designated as *bph2*. *Bph1* and *bph2* are closely linked. Later studies revealed that varieties with *Bph1* and *bph2* reacted differentially to different biotypes Athwal *et al.*, (1971). Two more varieties MGL 2 and Ptb 18 were studied by Athwal *et al.*, (1971) and found that MGL 2 possessed *Bph1* and Ptb 18 possessed *bph2*.

Martinez and Khush (1974) studied the inheritance in IR- lines and found that IR 747 B₂ – 6 had a dominant gene for resistance that was allelic to *Bph1* and IR 1154 – 243 has a recessive gene that was allelic to *bph2*. TKM 6, one of the susceptible parents of IR 747 B₂ – 6, when crossed with other susceptible varieties such as TN1, IR 20 or IR 24, yielded small proportion of progeny which were resistant to brown planthopper. Martinez and Khush (1974) concluded that TKM 6 was homozygous for *Bph1*.

Krishna (1977) studied the inheritance of brown planthopper resistance in 11 rice varieties and found that Ptb 33, ARC 6650, ARC 14636B, ARC 768 and Lua Ngu possessed dominant genes for resistance, whereas Ptb21, MR 1523, Umsum, Leb Mue Nahng, ARC 14394 and ARC 15694 had the recessive gene for resistance.

Lakshminarayan and Khush (1977) studied the inheritance of resistance in 28 rice varieties and identified two new loci for resistance. They reported that a single dominant gene conferred resistance in Rathu Heenati, but it segregated independently of *Bph1* and was designated *Bph3*. Similarly, a single recessive gene governed resistance in Babawee but it segregated independently of *bph2* and was designated *bph4*. The resistance in Ptb 21 was controlled by one dominant and one recessive gene.

Prasada Rao *et al.*, (1977) observed F₁, F₂ and F₃ populations of cross, RP 31-49-2 (susceptible) x Leb Muey Nahng (moderately resistant) under green house condition, and concluded that resistance to the nymphal stage of *Nilaparvata lugens*, was controlled by a single recessive gene.

Sujadi and Kush (1977) examined 500 F₃ lines derived from TN 1 x IR 2661-464-6 for endosperm type and resistance to *Xanthomonas oryzae*, *Nilaparvata lugens* and grassy stunt virus. The F₃ data fitted 1:2:1 ratio expected for monogenic control of each trait. A two-way classification indicated that it should be possible to recombine these four traits in various combinations in rice varieties.

Prasada Rao *et al.*, (1977) reported that the resistance of Leb Mue Nahng against brown planthopper was due to a single recessive gene.

Sidhu and Khush (1978) studied the inheritance of brown planthopper in 20 rice varieties and reported that one dominant and one recessive gene governed the resistance in Ptb 33, Sudu Hondarawala, and Sinna Sivappu, which segregated independently of each other. The dominant genes in these varieties are allelic to either *Bph1* or *Bph3*. Similarly, the recessive genes in these varieties are

allelic to either *bph2* or *bph4*. They also reported that *Bph3* and *bph4* are closely linked.

Pongprasert and Weerapat (1979) reported that the resistance to brown planthopper in rice varieties W 1252, WR 59 and W 1263 was conditioned by a single dominant gene.

Choi *et al.*, (1980) investigated the inheritance of brown planthopper in Mudgo and Co 22 in Korea and found that the resistance was governed by a single dominant gene.

Prasada Rao *et al.*, (1980) studied the inheritance of brown planthopper resistance in four rice varieties and found that resistance was controlled by a recessive gene in RP 1528, Rp 1607 and RP 1606 while in RP 1144, it was due to a dominant gene.

Ikeda and Kaneda (1981) studied the allelic relationships among four resistance genes *Bph1*, *bph2*, *Bph3* and *bph4*. They found that *bph2* as well as *Bph1* segregate independently of both *Bph3* and *bph4*; whereas, *Bph3* and *bph4* are closely linked. Therefore, the combination of *Bph1* with *Bph3*; *Bph1* with *bph4*, *bph2* with *Bph3*, or *bph2* with *bph4*, respectively in a variety could be achieved. On the basis of trisomic analysis they identified the loci of *Bph 3* and *bph4* on chromosome 10.

Lin (1981) analyzed the F₁ and F₂ of crosses between the susceptible and resistant lines. The results indicated that the resistance of Taichung-SenYu 223 was controlled by a single dominant gene, *Bph1*, which conferred resistance to biotype 1 and 3. Resistance to biotype 1 and in Taichungsen 10 is controlled by the recessive gene *bph2* and resistance to biotypes 1, 2, 3 and 5 in IR 13539-11-1

is controlled by the dominant gene *Bph3*. The recessive gene *bph4* in IR 17488-2-2-1 confers resistance to biotypes 1 – 4. *Bph1* and *bph2* are thought to be closely linked as are *Bph3* and *bph4*. It is concluded that in one variety either *Bph1* or *bph2* may be combined with *Bph3* or *bph4*.

Anonymous (1982) classified all the brown planthopper resistant varieties and reported that, susceptible varieties with *Bph1* gene are resistant to biotypes 1 and 3, whereas varieties with *bph2* have resistance to biotype 1 and 2. Varieties with *Bph3* and *bph4* are resistant to all biotypes with the possible exception of the Pantnagar population.

Huang *et al.*, (1982) made the cross between a japonica semi dwarf mutant (TNG 61 M₅10-1) and a resistant *Oryza rufipogon*, which was backcrossed several times to the mutant, were further crossed with two japonica varieties Tainung 62 and Tainan 6, resistant to *P. oryzae*. From F₅ of these crosses, 241 strains with combined resistance were identified. Analysis suggested that the gene controlling resistance to *Nilaparvata lugens* was either *Bph3* or an unidentified gene.

Ikeda and Kaneda (1982) located *Bph1* on chromosome 4. No linkage was detected between *Bph1*, on one hand and *lg* and *d-11* markers of chromosome 4 on the other. However, *bph2* was found linked with *d-2* with a 39.4% recombination value.

Ikeda and Kaneda (1982) reported that the resistance in Andragahwewa and Ptb 34 was controlled by *Bph1* and *bph2* respectively but the resistance in Ptb21 appeared to be controlled by *bph2* and *Bph3*. Results of trisomic analysis revealed that *Bph3* and *bph4* were located on chromosome 7.

Lin (1982) screened varieties for resistance to 5 biotypes of *Nilaparvata lugens* in 1979-81, the study indicated that Taichungenshih 329 might carry the recessive resistance gene *bph4* and Taichungenshih 339 and 338 dominant resistance gene *Bph3*.

Ikeda and Kaneda (1983) studied F_2 segregation ratios for resistance in crosses between 5 out of 9 trisomic lines and Kanto PL 1 or Kanto PL 4, both carrying *Bph1*, their study indicated that *Bph1* was located on chromosome 11 (equivalent to linkage group II). Linkage analysis of the allelic or closely linked genes *Bph 1* and *bph2* including the study of a cross between F_1 202 (carrying P_{11} - Purple leaf) *lg* (linguleless) and d_2 (ebisu dwarf) and F_4 203 (carrying *bph2*) revealed that *lg*, P_{11} and d_{11} were independent of *Bph1* and *bph2* is linked with d_2 with a recombination value of 39.4 %.

Krishna and Sheshu (1984) studied the F_2 generation from 30 crosses between 24 *Nilaparvata lugens* resistant and the susceptible cultivars, Jaya, TN1 and RP633-519 and concluded that resistance is controlled by a single dominant gene in 5 cultivars by a single recessive gene in 9 cultivars and duplicate dominant gene, in 10 cultivars. In progenies from TN1 x Ptb33, a highly significant association was found between resistance and red pericarp but no association was found between resistance and 5 other characters, including yield.

Chelliah (1985) reported that resistance to *Nilaparvata lugens* is controlled by major genes *Bph 1*, *bph 2*, *Bph 3* and *bph 4*, the last two being either allelic or closely linked.

Ikeda (1985) analysed the crosses between resistant cultivars carrying resistance genes. The analysis suggested that *Bph1* and *bph2* were linked, as were

Bph3 and *bph4*, but that the 2 linkage groups were independent. A study of 27 marker genes belonging to 11 linkage groups showed that *bph2* was weakly linked with d-2 in linkage group II. *Bph1* was located on chromosome 11 (linkage group II), conferring the *bph2* / d-2 linkage, which had an estimated recombination value of 39.4 %. *Bph3* and *bph4* were located on chromosome 7 while *bph4* was linked with MC-2 with a recombination value of 30.3 %. Crosses involving the resistant *indica* varieties Anakragahaweloa, Ptb34 and Ptb21 established that the first has *Bph1*, the second *bph2* and third *bph2* and *Bph3*.

Ikeda (1985) reported that Balamawee (70-518), Kaharamana, Col 11 Thailand and Chin Saba had an unknown recessive gene and Balamawee (70-164), Ptb 7, Ptb 12 and Ptb 20 had one dominant and one recessive gene.

Ikeda and Kaneda (1985) reported that Balamawee (70-518), Kaharamana and Pokkali had an unknown dominant gene; Col. 5 Thailand, Col. 11 Thailand and Chin Saba an unknown recessive gene whereas Balamawee (70-164), Ptb 7, Ptb 12 and Ptb 20 had one dominant and one recessive genes.

Vellusamy and Chelliah (1985) studied the genetics of resistance in rice varieties ASD 11, IET 5741, IET 6315, T 7 and V.P. Samba to attack by the *Nilaparvata lugens* in India. Resistance was shown to be dominant in all these varieties and conditioned by a single dominant gene. The study of F₃ generation of 2 varieties confirmed the monogenic nature of resistance in V.P. Samba.

Angeles *et al.*, (1986) confirmed the control of brown planthopper resistance by two genes (*Bph 3* and *bph 2*) in Ptb 21 and Ptb 33.

Khush *et al.*, (1986) found that resistance to brown planthopper in rice cultivar ARC 10550 was governed by a single recessive gene which was

designated *bph5*. It confers resistance to brown planthopper population in South Asia, but not against populations occurring in East and South East Asia. This gene segregated independently of four known genes for brown planthopper resistance. It could be possible to combine this gene with a broad spectrum of resistance.

Prasada Rao and Kalode (1987) studied the inheritance and interrelationships of genes governing brown planthopper resistance with purple pigmentation in the coleoptile and leaf blade in three crosses. Resistance to brown planthopper was due to three dominant complementary genes, *bph5* (*t*), *bph6* (*t*) *Bph7* (*t*) and coleoptile pigmentation due to two dominant complementary genes, *Pc1*, *Pc2* in the cross RP 1748 (Leb Mue Nahng, Brown planthopper susceptible, coleoptile green) ARC 6650 (Brown planthopper resistant, coleoptile purple). In the cross RP 1578, ARC 7328 (Brown planthopper susceptible, coleoptile purple) with CR 57 MR 1523 (Brown planthopper resistant, coleoptile green), resistance to brown planthopper was due to two recessive complementary genes, *bph8* (*t*) and *Bph9* (*t*) and pigmentation in the coleoptile was due to two complementary genes. The genes were independent of each other. In cross RP 2205 involving ARC 5723 (Brown planthopper susceptible, leaf purple and coleoptile with ARC 6650 (green leaf)) the F_1 was brown planthopper resistant with pigmented coleoptile and green leaf. Resistance to brown planthopper was due to two dominant complementary genes. The gene for purple leaf showed interaction with *I-P1* and a ratio of 3 green: 13 purple leaves was observed in F_2 . The genes for coleoptile pigment were common in both parents. One of the genes for brown planthopper resistance showed linkage

with the inhibitor gene for purple leaf *I-Pl* with a C.O. value of 44.72% in the repulsion phase. The gene for purple leaf *Pl* was independent to the gene(s) for brown planthopper resistance. From the results obtained it was concluded that the linkage sequence of genes for purple coleoptile *PC1 / PC2-bph5 (t) / bph6 (t) / Bph7 (t) - I - Pl* belong to the II linkage group of *Oryza sativa* var. *indica*.

Prasada Rao *et al.*, (1987) studied inheritance of genes governing brown planthopper in 15 crosses involving six susceptible varieties, RP 193-1, Prakash, Swarnadhan, Vikram, TKM 6, IR 8 and five resistant donors, Ptb 33, Andrewsali, Velluthacheera, CR-57-MR 1523 (MR 1523) and Ptb 21. Based on the results obtained in F_1 through F_3 generations, brown planthopper resistance was found to be governed by two dominant complementary genes, *bph5 (t)*, *bph6 (t)* in Ptb 33 and two dominant complementary genes, *bph6 (t) bph9 (t)* controlled resistance in Ptb21 and MR 1523; one of these genes is common to TKM 8. The F_1 hybrids as well as F_2 and F_3 progenies of susceptible x susceptible parents did not segregate for brown planthopper resistance, likewise, crosses between resistant parents Ptb 33, Andrewsali, and Velluthacheera as well as Ptb 21 with MR 1523 showed no segregation for brown planthopper resistance in F_1 , F_2 and F_3 generations, indicating that the genes are common.

Anwarul Kabir and Khush (1988) genetically analyzed 17 rice cultivars resistant to *Nilaparvata lugens*. The study revealed that 7 cultivars were found to have different single dominant gene for resistance which, segregated independently of the recessive gene *bph 5*. The resistant gene of the cultivar Swarnalata was designated *Bph 6*. Also in 10 cultivars the resistance was governed by single recessive genes. Out of these cultivars, the resistance genes

were allelic to *bph 5*. Whereas the recessive gene of one of the remaining two, T12 is designated *bph 7*.

Murthy *et al.*, (1988) found that in ARC 11351 resistance to brown planthopper was controlled by a single recessive gene. In Velluthacheera and Ptb 21 resistance was governed by one dominant and one recessive gene which segregated independently. ARC 6650 carried duplicate dominant genes, which segregated independently of each other.

Velusamy and Saxena (1989) reported that *Bph 1* and *bph 2* genes did not confer resistance against the population of *Nilaparvata lugens* (Stål) in Tamil Nadu. Varieties with *Bph3*, *bph4*, *bph5* and *Bph6* and *bph2* plus *Bph3* genes had high levels of resistance.

Prasad *et al.*, (1990) investigated on mixed population of brown planthopper and white backed planthopper and reported that the resistance was due to dominant nature of brown planthopper over white backed planthopper.

Ishii *et al.*, (1994) reported a resistance gene *Bph 10 (t)* from the *Oryza australiensis* and located its position on rice chromosome 12 linked with a marker RG 457 at a distance of 3.68 cM.

Hirabayashi and Ogawa (1996) carried out the RFLP analysis to determine the chromosome location and the locus of the brown planthopper resistance gene *Bph 1* on linkage map of rice. The study revealed that the *Bph1* was linked with 7 markers and 8 loci were arranged in the order, *Bph 1*, *XNpb 248*, *XNpb 304-1*, *XNpb 319*, *XNpb 304-2*, *XNpb 336*, *XNpb 316*, and *G 124-1*.

Tomar and Prasad (1996) reported that the resistance to brown planthopper was governed by a single dominant gene in BG 379-4, IET 7944,

IET 7946 and BG 379-1; a single recessive gene in MTU 5195 and RP 2075-5-7-32; three dominant genes in Ptb33 and IR 1960-274-3-3-1; two dominant complementary genes in IR 17488-2-3-2 and CR 57 MR 1523 ; inhibitory gene in Babawee and CR 266-407-6-1 ; two duplicate dominant genes in MTU 5295 and Rathu Heenati and three dominant complementary genes in IET 7947.

Cha Young Soon *et al.*, (1999) studied the cultivars Mudgo and Sangju 13 for mapping of *Bph 1* and *bph 2* genes. *Bph 1* was mapped between RG 413 and RG 901 on chromosome 12 at a distance of 14.4 cM. *Bph 1* and *bph 2* were linked to each other with a distance of about 30 cM. An RFLP marker RG 413 linked to *Bph 1* was converted to an STS marker to facilitate marker – assisted selection.

Verma *et al.*, (1999) made crosses involving 13 accessions having resistance to brown planthopper, with susceptible variety TN1. In all cultivars resistance to brown planthopper was controlled by 2 dominant and 2 recessive genes.

Xu XiaoFeng *et al.*, (1999) evaluated rice recombinant inbred lines (RIL) of the cross Lemont / Teqing for resistance to brown planthopper (*Nilaparvata lugens*). Some 160 tested RIL gave a continuous distribution in their resistance in the tested rice plants to brown planthopper indicating the polygenic type of resistance.

Crosses were made among brown planthopper resistant and susceptible genotypes and segregating populations were screened for brown planthopper resistance under greenhouse condition to study the genetics of resistance. Velluthacheera, T147, T1426 and T1432 were found to have 2 dominant genes

conferring brown plant hopper resistance. F₂ plants from crosses involving these genotypes and Rathu Heenati and IR 72 did not segregate for resistance. This indicated that the resistant genes present in these genotypes were allelic to the dominant genes *Bph 3* and *Bph 6*. Intercrosses among the above-mentioned genotypes also did not show segregation in F₂ generation, indicating that genes imparting resistance in Velluthacheera, T147, T1426 and T1432 were mutually allelic. In another set of crosses the recessive gene in ARC 5984, Manoharsali, Sonasali, Nagarjuna imparting brown planthopper resistance was found to be allelic to the known recessive gene *bph 4* present in Babawee. Results obtained in all the above crosses were confirmed from studies in F₃ generation. In the third set of crosses, the dominant resistant gene in ARC 14529, ARC 10550 and ARC 14771 was found allelic to *Bph 6* present in IR 72, Anonymous (2000).

Liu Guo Qing *et al.*, (2000) carried out the segregation analysis, RFLP and micro satellite mapping of the new resistant gene *Bph 11 (t)*, which was located between RM 240 and RM 250 on rice chromosome 2. This resistant gene was reported from the *Oryza eichingeri*, wild brown plant hopper resistant rice from Africa.

Kawaguchi *et al.*, (2001) studied two cross combinations involving Babawee (*bph 4* gene) and IR 24 and Tsukushibare. On the basis of bulked segregant analysis and linkage analysis, the *bph 4* gene was assigned to the distal region of the short arm of rice chromosome 6.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The study entitled "Genetic Analysis of Resistance to Brown Planthopper, *Nilaparvata lugens* (Stål) in some Selected Rice Varieties" was carried out in the Department of Plant Breeding and Genetics, Indira Gandhi Agricultural University, Raipur during *kharif*, 2000, *Rabi-Summer*, 2000-2001 and *Kharif* 2001. The university research farm is located at 20.6° N latitude and 81.36° E longitude and at an altitude of 289.56 meters above mean sea level.

3.1 Experimental material:

The study was carried out in three parts.

Part I: Screening of rice accessions against Indian biotype of brown planthopper, *Nilaparvata lugens* (Stål). 13 viz., ARC 10550, Chaitanya, Suraksha, Chandan, Nagarjuna, IET 14074, IET 12537, IET 8116, MTU 1001, BG-380-2, Triguna, TN 1 and Swarna accessions maintained by Department of Plant Breeding and Genetics, IGAU, Raipur were screened using standard seed box method for their resistance against the existing brown planthopper population of Raipur. Table 3.1 contains the list of 13 accessions used in this study.

Part II: BG-380-2 and Triguna were recorded susceptible, so were not included in the further studies. The study was planned to determine the mode of inheritance of resistance in selected genotypes viz., ARC 10550, Chandan, Chaitanya, Suraksha, Nagarjuna, IET 14074, IET 12537, IET 8116 and MTU 1001. Out of these accessions ARC 10550, Chandan, IET 8116 and IET 12537 were crossed with known susceptible variety TN1, whereas ARC 10550, MTU

1001, Chaitanya, Nagarjuna, IET 8116, Suraksha, IET 14074 were crossed with other susceptible variety Swarna.

Part III: Allelic study was made by crossing resistant x resistant genotypes. The F₁ and F₂ generations were analysed for allelic study.

Table: 3.1 Varieties used for study

Name	IET No.	Parents	Year of release	50% flow.	Ecosy stem *	Grain type..
Swarna	7041	Vasishtha / Mahsuri	1982	125	RSL	MS
Chaitanya	9265	Sowbhagya / ARC 5984	1988	120	RSL	MS
Chandan	11450	Sona / Manoharsali	1989	120	RSL	LS
Nagarjuna	6315	Sona / Manoharsali	1988	120	RSL	LS
MTU 1001	13967	MTU 5249 / MTU 7014	1995	110	IRM	LB
IET 8116	8116	Vikram / Andrewsali	1998	100	IRM	LB
Suraksha	7946	Sasyasree / CR 57-MR 1523	1988	103	IRM	LB
Triguna	12875	Swarnadhan / RP 1579-38	1997	98	IRM	LS
TN 1		De-Gee-Woo-Gene/ Tsaiguchung	1969			
BG 380 - 2	15179	BG-90-2 / OB-677		100	IRM	LB
IET 14074	14074	Ratna / ARC- 10654		116	SHW	LS
RP-2332-16-13	12537	Ratna / ARC- 17654	1994	129	SHW	LS
ARC 10550						

*** Ecosystem**

RSL : Rainfed Shallow Lowland
IRM : Irrigated Medium
SHW : Shallow water

**** Grain Type**

LB : Long Bold
LS : Long Slender
MS : Medium Slender

All the crosses were made during *kharif*, 2000 following standard procedure. The emasculation was done with the help of vacuum emasculator during evening hours. The pollens from required parent was collected in the following morning and dusted on the stigma of emasculated female parents.

3.2 Advancing of generation:

The F_1 's of all the crosses included in part II and part III was grown during *Rabi-summer* 2000-2001 to raise F_2 generation.

3.3 Handling of Hybrid Population:

At least 40 F_1 seeds were produced for each cross. F_1 seeds were harvested at about 25-30 days after pollination and were sun dried for 3-4 days. Seeds were individually hand threshed and kept in coin envelopes.

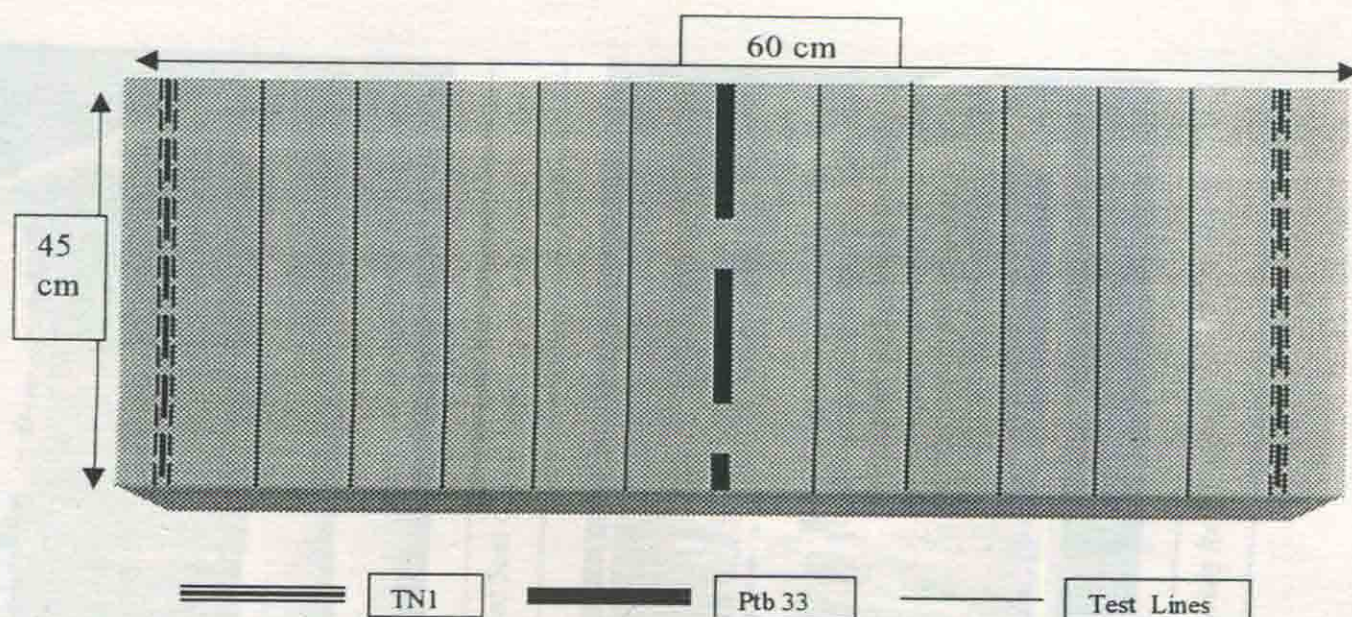
Prior to sowing, F_1 seeds were treated with Bavistin @ 0.25%. These disinfected seeds were planted in petri dishes lined with moist filter paper on 02-02-2000 and kept in germinator at 30° C for 48 hrs. The germinated seeds were first planted in the wooden trays (seed boxes) on 04-02-2000 and later on seedlings were transplanted on the platforms constructed in the Department, after 25 days at 25 X 20 cm² spacing on 29-02-2000 to avoid rat damage and proper growth of seedlings. The F_1 plants were checked regularly during different stages of growth and off types and self's were removed F_2 seeds were harvested separately from individual plants of each cross.

3.4 Parents, F_1 's and F_2 's:

The parents, F_1 's and F_2 's of each cross were screened against the Indian biotype of brown planthopper in the green house of Directorate of Rice Research during *Rabi 2001* replicated twice.

The insect populations of Indian biotype collected from the fields of Directorate of Rice Research were used to develop the insect population using the standard cage rearing system. The same insect population was used to screen the parents, F_1 's and F_2 's of each cross using the standard seed box technique.

3.5 Green house screening:



Standard Seed box Screening Technique for Brown Planthopper *Nilaparvata lugens* (Stål)

Green house screening is usually done at seedling stage. It is a very efficient screening method for evaluating a large number of breeding lines. The Standard Seed Box screening technique was used to screen the F_2 population. Parents, F_1 , F_2 populations were screened at Directorate of Rice Research, Hyderabad, green house. To test the F_2 material, the test lines were seeded in rows 5 cm apart in 60 cm X 45 cm X 10 cm seed boxes. Each line was planted in a 20 cm long row demarcated along the width of the seed box. Also, the outer rows in each seed box were planted with TN 1 (susceptible check) to prevent escapes. A known local resistant check (Ptb 33) planted in a single row across the center of the seed box helped in accessing the insect pressure. The varieties in Table 1.2 can be used as susceptible and resistant checks for different biotypes of brown planthopper.

The seed boxes were then placed in a 1.5 m X 4.0 m X 0.1 m galvanized

iron tray on a table inside green house. The tray which consisted about 3 cm

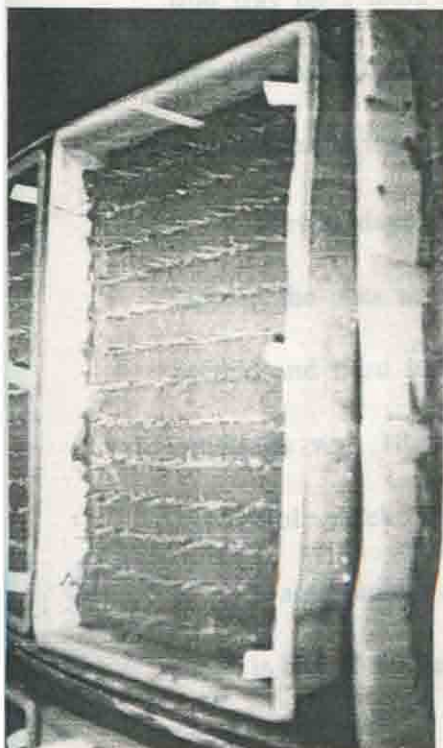


Plate No. 5 Germinated Seed of Test Line

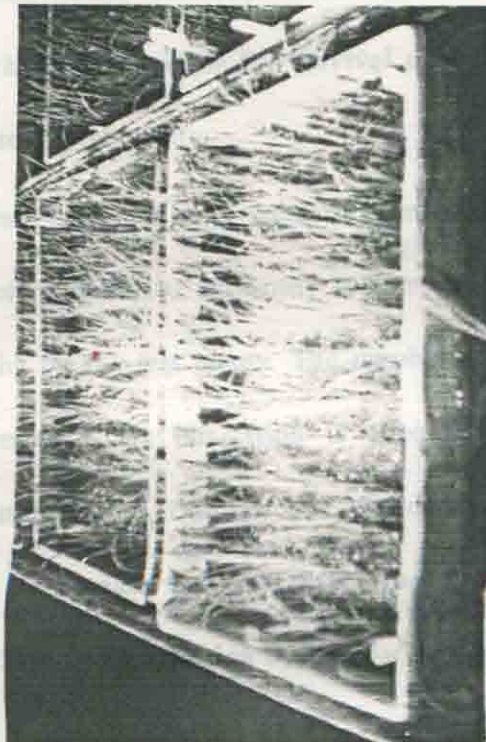


Plate No. 7 Seedlings Ready for Infestation

Screening of F₁ at Directorate of Rice Research, Hyderabad

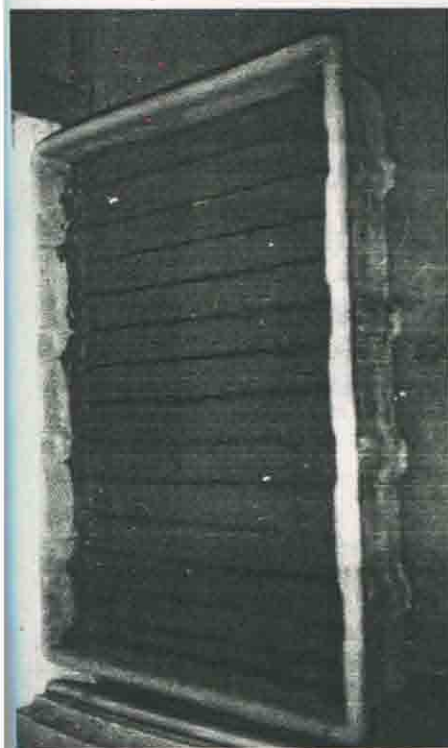


Plate No. 4 Seed Box Prepared for Screening

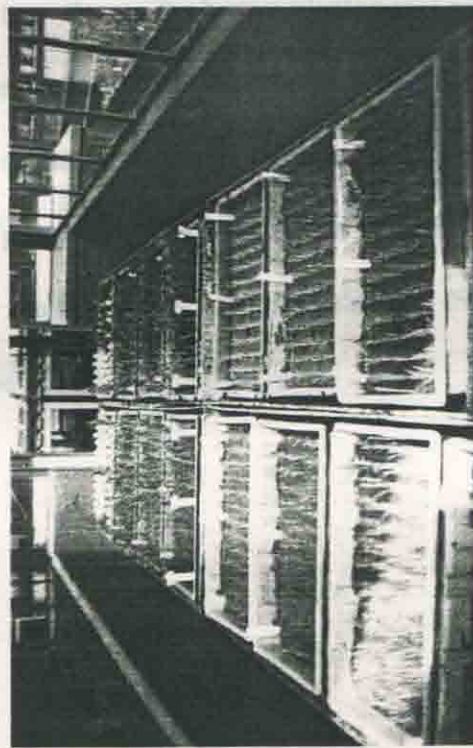


Plate No. 6 Two Stages of Germinated Seeds

The seed boxes were then placed in a 1.5 m X 4.0 m X 0.1 m galvanized iron tray on a table inside green house. The tray, which contains about 5 cm standing water, provides high humidity suitable for survival of the insects and also eliminates the need for watering the plants.

Seven days after sowing, the seedlings were then infested by gently tapping the pots with the insect colonies to uniformly scatter large number of second and third instar nymphs on the test plants. The number of insects per seedlings was 10 on an average. This infestation is adequate to kill the susceptible check lines in about 7-10 days. Damage was recorded on a row basis for F_1 's and parents and on a single plant basis for F_2 's, when the susceptible check is killed, on the basis of Standard Evaluation System for Rice (IRRI, 1980, 1988).

Screening of F_2 at Directorate of Rice Research, Hyderabad:

The DRR follows only two classes for brown planthopper screening. One resistant (the survived plants) and other susceptible (the dead plants). This is little different from the Standard Evaluation System (IRRI, 1988). Therefore for the present study screening of the parents at Raipur score less than 5 was considered to be moderate resistant as against the Standard Evaluation System (IRRI, 1988). For the present study, the scores recorded were

Resistant < 3

Moderate Resistant 3-5

Susceptible > 5

3.6 Inheritance study:

F₁ and F₂ populations were analysed to study the mode of inheritance following χ^2 (Chi - Square Test) as suggested by Fisher, R. A. (1936).

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i}$$

Where, E_i = Expected frequency of ith class

O_i = Observed frequency of ith class

With (n-1) = degree of freedom.

The calculated values of χ^2 (Chi - Square) were compared with tabulated values for (n-1) degrees of freedom. If the calculated value of χ^2 for (n-1) df at 5% level of significance was less than the table values, then the difference between observed and expected values were treated to be non - significant.

For genetical analysis the frequencies HR, MR and R categories were treated as resistant (R) and MS, S and HS pooled together were treated as susceptible (S).

3.7 Allelic Tests:

The crosses among resistant x resistant parents were studied in F₂ for segregation. The non-segregating population would reveal the allelic relationship between the resistant genes, whereas those segregating as resistant and susceptible in F₂ were considered to be non-allelic.

RESULTS

CHAPTER IV

RESULTS

The results obtained from the present study on "Genetic Analysis of Resistance to Brown Planthopper, *Nilaparvata lugens* (Stål) in Some Selected Rice Varieties" are presented under following subheads:

1. Screening was made with available biotype to confirm the earlier reports.
2. Mode of inheritance of brown planthopper resistance in selected genotypes against Indian Biotype.
3. Allelic relationship among the gene(s) for resistance present in genotypes under study.

4.1 Insect reactions on varieties / genotypes :

Eleven rice varieties earlier reported to be resistant against the mixed biotype (at Raipur) of brown planthopper were further screened and their reactions are presented in table 4.1. Out of these, IET 12537, IET 14074, Chandan, Nagarjuna and Suraksha, were found to be resistant with a score below 3. Four varieties IET 8116, Chaitanya, MTU 1001 and ARC 10550 with score < 5 score were moderately resistant. Two varieties viz., Triguna and BG-380-2 with a score of 6.31 and 6.91, respectively were observed to be susceptible.

4.2 Mode of inheritance of brown planthopper resistance:

The mode of inheritance was studied in 9 varieties viz., ARC 10550 (3.54) Chandan (2.66), IET 8116 (4.81), IET 12537 (2.34), MTU 1001 (4.35), Chaitanya (3.67), Nagarjuna (2.54), Suraksha (1.88) and IET 14074 (2.39), which were observed to have < 5 score in the greenhouse test. These were crossed with

Table: 4.1 reaction of varieties against Indian Biotype of *Nilaparvata lugens* (Stål).

Sr. No.	Variety	Insect Damage Score				Reaction
		I	II	III	Average	
1	IET 14074	2.50	2.63	2.04	2.39	R
2	Triguna	6.30	7.20	5.43	6.31	S
3	IET 8116	4.83	5.00	4.60	4.81	MR
4	Chaitanya	3.44	4.10	3.47	3.67	MR
5	Suraksha	2.00	1.70	1.94	1.88	R
6	MTU 1001	4.00	4.80	4.25	4.35	MR
7	IET 12537	2.09	2.63	2.30	2.34	R
8	BG-380-2	6.27	7.30	7.16	6.91	S
9	Nagarjuna	2.15	2.74	2.73	2.54	R
10	Chandan	2.47	2.96	2.55	2.66	R
11	ARC 10550	3.33	3.87	3.42	3.54	MR

known susceptible varieties, TN 1 or Swarna. Since TN 1 is a early variety and resistant varieties were late maturing therefore all crosses could not be attempted with TN 1, therefore only four accessions viz., ARC 10550 Chandan, IET 8116, IET 12537 were crossed with TN 1 and ARC 10550, MTU 1001, Chaitanya, Nagarjuna, IET 8116, Suraksha, IET 14074 were crossed with another susceptible variety Swarna. Varieties BG 380-2 and Triguna, earlier reported to be resistant were found susceptible while screening, hence were not incorporated in the inheritance studies. The crosses made between susceptible and resistant varieties, their F_1 and F_2 reactions against brown planthopper are presented in Table 4.2

The F_1 plants of the crosses of TN 1 with IET 8116 and that of Swarna with MTU 1001, IET 8116 and Suraksha were all resistant indicating that the resistance is dominant over susceptibility. These crosses in F_2 generation segregated in the ratio of 3 resistant: 1 susceptible, indicating that a dominant gene governed the resistance in IET 8116, MTU 1001 and Suraksha. (Appendix 1)

The F_1 of crosses of ARC 10550 with both TN1 and Swarna showed resistant reaction and a good fit ratio of 3 resistant:1 susceptible in F_2 , indicating that the resistance in ARC 10550 was governed by single dominant gene (Table 4.2). (Appendix 1)

The F_1 's of Swarna with Nagarjuna and TN 1 with IET 12537 were susceptible indicting the recessive nature of resistance. In F_2 a good fit ratio of 1 resistant: 3 susceptible were observed indicating that recessive gene governed the resistance in Nagarjuna and IET 12537. (Appendix 2)

Table: 4.2 Reaction of *Nilaparvata lugens* (Stal) in F₁ and F₂ of crosses between susceptible x resistant varieties.

No.	Name	Reaction of F ₁	Total	Resistant	Susceptible	X ² Value	Ratio	P Value
1	TN1 x Chandan	Susceptible	320	140	180	0.32	7:9	0.90-0.80
2	TN1 x IET - 8116	Resistant	263	193	70	0.36	3:1	0.90-0.80
3	TN1 x IET - 12537	Susceptible	272	72	200	0.31	1:3	0.90-0.80
4	TN1 x ARC 10550	Resistant	321	247	74	0.64	3:1	0.80-0.70
5	Swarna x MTU - 1001	Resistant	357	275	82	0.73	3:1	0.70-0.50
6	Swarna x Chaitanya	Resistant	378	219	165	0.39	9:7	0.90-0.80
7	Swarna x Nagarjuna	Susceptible	387	98	289	0.02	1:3	0.99
8	Swarna x IET - 8116	Resistant	346	252	94	0.86	3:1	0.70-0.50
9	Swarna x Suraksha	Resistant	307	228	79	0.08	3:1	0.99-0.98
10	Swarna x IET - 14074	Resistant	330	176	144	0.31	9:7	0.90-0.80
11	Swarna x ARC 10550	Resistant	346	256	90	0.18	3:1	0.95-0.90

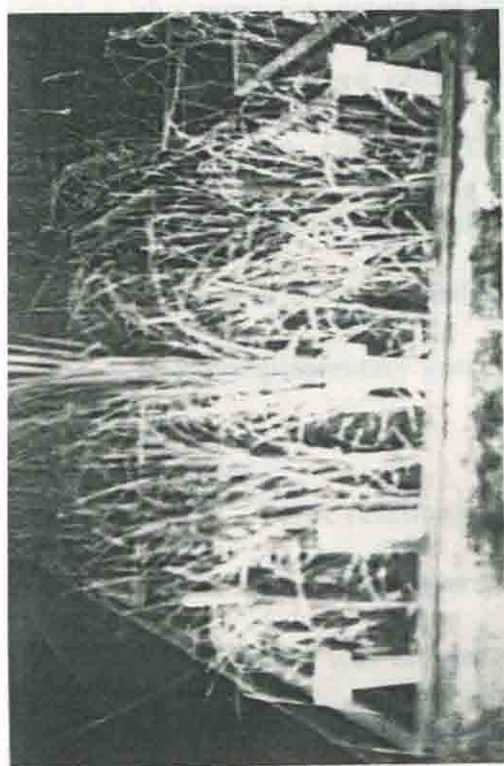


Plate No. 9 Cross-Between TN 1 x IET 12537

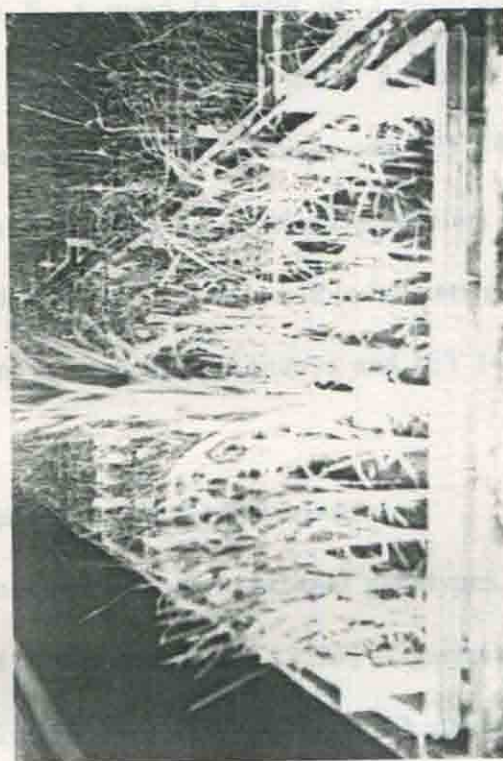


Plate No. 11 Cross-Between Swarna x Chaitanya

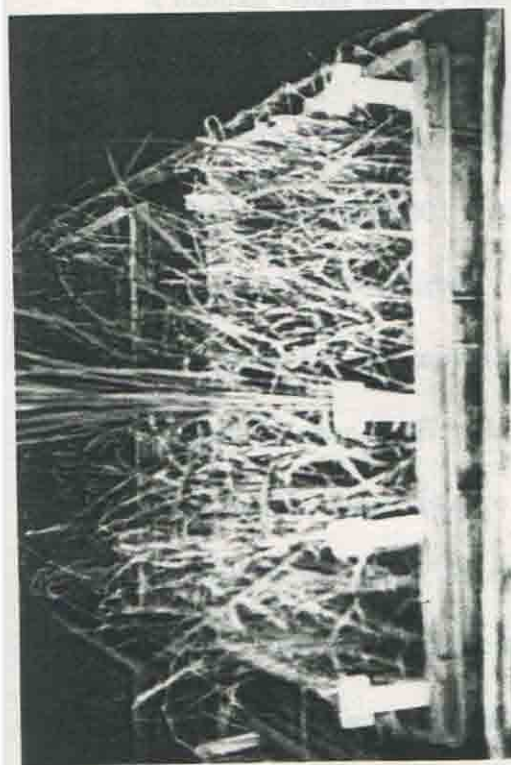


Plate No. 8 Cross-Between TN 1 x IET 8116

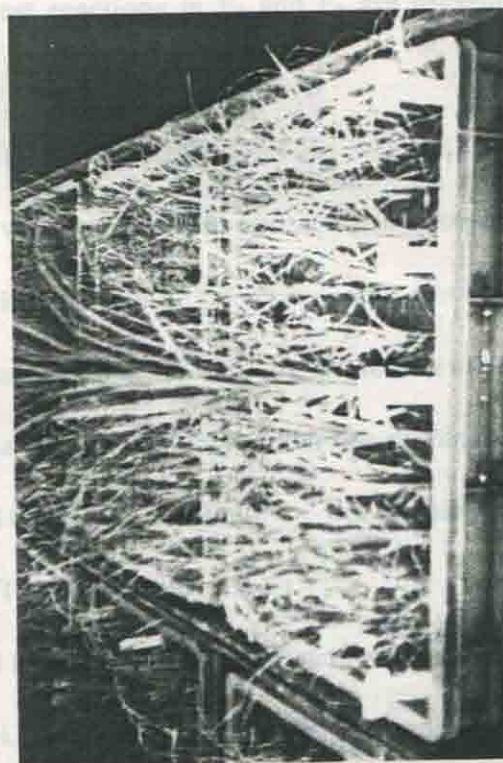


Plate No. 10 Cross-Between Swarna x MTU 1001

The F_1 plants of the cross TN 1 with Chandan were susceptible indicating the recessive nature of resistance. In F_2 a good fit ratio of 7 resistant: 9 susceptible were observed indicating that two recessive genes governed the resistance in Chandan. The F_2 's of the Swarna with Chaitanya and IET 14074 were resistant indicating that resistance is dominant over susceptibility. The crosses in F_2 segregated in the ratio of 9 resistant: 7 susceptible indicating that two complementary genes governed the resistance in Chaitanya and IET 14074. (Appendix 3 and 4)

4.3 Allelic relationships among gene(s) conferring resistance:

Allelic tests were made by crossing resistant x resistant genotypes. The ARC 10550 was crossed with IET 8116, Suraksha, IET 12537, Nagarjuna and MTU 1001. The crosses between ARC 10550 with IET 14074 and Chandan were attempted, but the F_1 could not be raised satisfactorily, therefore IET 14074 and Chandan could not be studied. The pest reactions in F_1 and F_2 are presented in Table 4.3.

The F_1 plants of the crosses IET 8116 x ARC 10550, Suraksha x ARC 10550 and MTU 1001 x ARC 10550 were all resistant and in F_2 they segregated in a ratio of 15 Resistant: 1 Susceptible, indicating that resistance is governed by two genes i.e. one known dominant gene present in ARC 10550 and an additional dominant gene in IET 8116, Suraksha and MTU 1001. Thus the dominant gene responsible for resistance in ARC 10550 is non-allelic to the dominant gene present in IET 8116, Suraksha and MTU 1001 (Appendix 6).

The F_1 of the cross IET 8116 with IET 12537 was resistant and F_2 generation segregated in a ratio of 13 Resistant: 3 Susceptible, indicating that

Table 4.3 Reaction of *Nilaparvata lugens* (Stål) in F₁ and F₂ of crosses between resistant and resistant varieties

No.	Name	Reaction of F ₁	Total	Resistant	Susceptible	X ² Value	Ratio	P Value
1	IET - 8116 x IET - 12537	Resistant	384	306	78	0.615	13:3	0.80-0.70
2	IET - 8116 x Suraksha	Resistant	386	356	30	1.52	15:1	0.50-0.30
3	IET - 8116 x Chandan	Resistant	736	627	109	0.34	55:9	0.90-0.80
4	IET - 8116 x IET - 14074	Resistant	424	372	52	0.76	57:7	0.70-0.50
5	IET - 8116 x ARC 10550	Resistant	427	392	35	2.763	15:1	0.30-0.20
6	Suraksha x Nagarjuna	Resistant	438	351	87	0.356	13:3	0.99-0.98
7	Suraksha x IET - 14074	Resistant	404	350	53	2.03	57:7	0.50-0.30
8	Suraksha x Chandan	Resistant	248	210	38	0.326	55:9	0.90-0.80
9	Suraksha x ARC 10550	Resistant	361	332	29	1.958	15:1	0.50-0.30
10	IET - 12537 x IET - 14074	Resistant	341	215	126	2.65	43:21	0.30-0.20
11	IET - 12537 x Suraksha	Resistant	265	200	65	5.42	13:3	0.10-0.05
12	IET - 12537 x Chaitanya	Resistant	341	228	113	0.016	43:21	0.99
13	IET - 12537 x ARC - 10550	Resistant	285	227	58	0.478	13:3	0.98-0.95
14	Nagarjuna x IET - 14074	Resistant	333	220	113	0.190	43:21	0.95-0.90
15	Nagarjuna x ARC - 10550	Resistant	421	350	71	0.982	13:3	0.70-0.50
16	MTU - 1001 x Nagarjuna	Resistant	302	249	53	0.286	13:3	0.90-0.80
17	MTU - 1001 x IET - 14074	Resistant	344	308	36	0.079	57:7	0.99-0.98
18	MTU - 1001 x ARC - 10550	Resistant	385	365	2070	0.732	15:1	0.70-0.50
19	Chandan x IET - 12537	Susceptible	407	233	174	0.053	37:27	0.99-0.98
20	Chandan x IET - 8116	Resistant	424	358	66	0.698	55:9	0.80-0.70

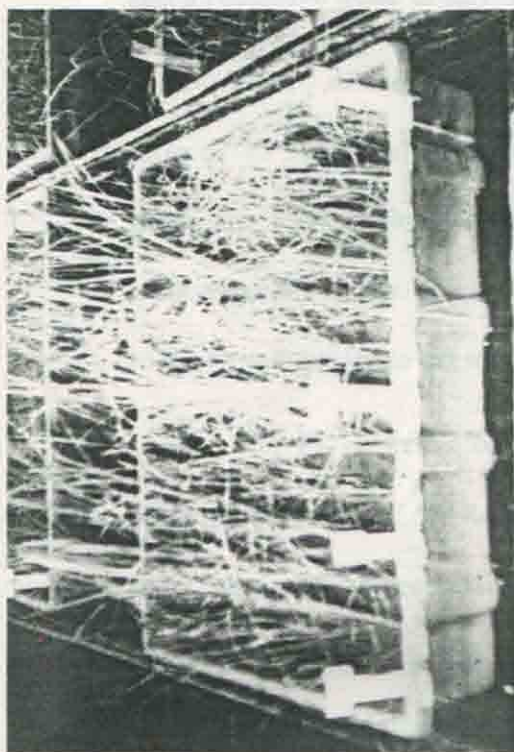


Plate No. 13 Cross-Between IET 8116 x IET 12537

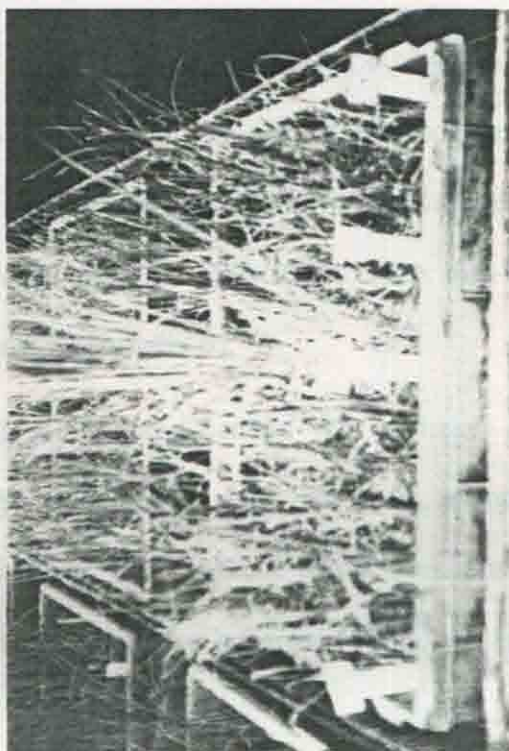


Plate No. 15 Cross-Between IET 8116 x IET 14074

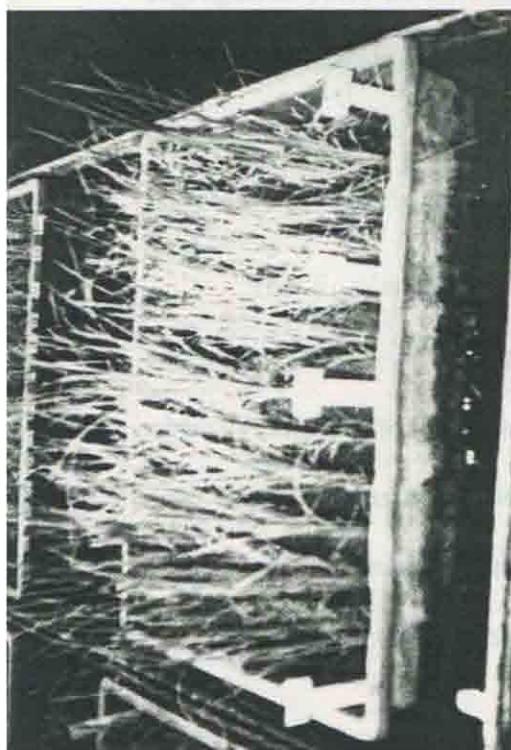


Plate No. 12 Cross-Between Suraksha x ARC 10550

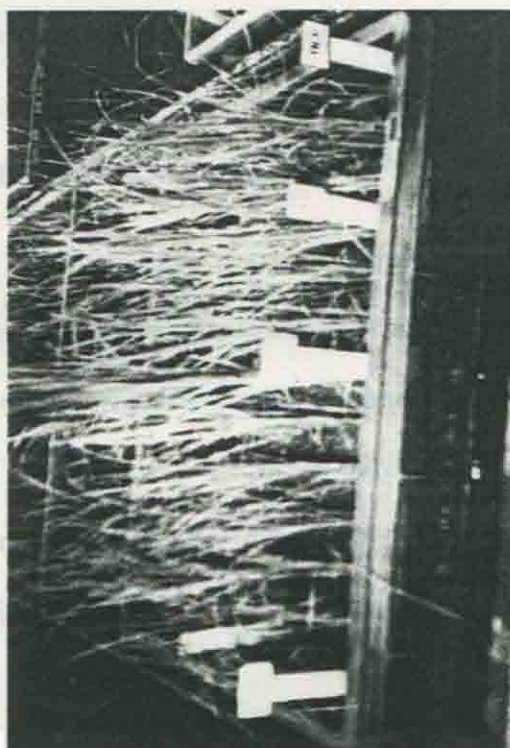


Plate No. 14 Cross-Between IET 8116 x Suraksha

resistance is governed by two genes i.e. one dominant gene present in IET 8116 and a recessive gene in IET 12537 which are non-allelic (Appendix 5).

The F_1 of cross IET 8116 with Suraksha was resistant. In F_2 a segregation ratio of 15 Resistant: 1 Susceptible was observed indicating that two dominant genes are involved in the inheritance of resistance. One from IET 8116 and other gene from Suraksha. Thus, the dominant gene present in IET 8116 is non-allelic to the dominant gene present in Suraksha (Appendix 6).

The F_1 of cross between IET 8116 and Chandan was resistant and a segregation ratio of 55 Resistant: 9 Susceptible was obtained in F_2 , suggesting that 3 genes were responsible for resistance. One of these was a dominant gene present in IET 8116 and the other parent Chandan possessed two independent recessive genes (Appendix 10).

The F_1 of cross IET 8116 x IET 14074 was resistant and in F_2 a segregation ratio of 57 Resistant: 7 Susceptible was obtained suggesting that 3 genes were involved in the inheritance of resistance. One of these genes was a dominant gene from IET 8116 and the other two complementary dominant genes which are present in other parent i.e. IET 14074 (Appendix 9).

The F_1 plants from the cross between Suraksha and Nagarjuna were all resistant, and in F_2 a segregation ratio of 13 Resistant: 3 Susceptible was observed indicating that two genes were involved in the inheritance of resistance. One of these was a dominant from Suraksha and the other parent has another independent recessive gene for resistance. Thus, the dominant gene present in Suraksha and recessive gene present in Nagarjuna were non-allelic. (Appendix 5).

Table 4.3 Reaction of *Nilaparvata lugens* (Stål) in F₁ and F₂ of crosses between resistant and resistant varieties

No.	Name	Reaction of F ₁	Total	Resistant	Susceptible	X ² Value	Ratio	P Value
1	IET - 8116 x IET - 12537	Resistant	384	306	78	0.615	13:3	0.80-0.70
2	IET - 8116 x Suraksha	Resistant	386	356	30	1.52	15:1	0.50-0.30
3	IET - 8116 x Chandan	Resistant	736	627	109	0.34	55:9	0.90-0.80
4	IET - 8116 x IET - 14074	Resistant	424	372	52	0.76	57:7	0.70-0.50
5	IET - 8116 x ARC 10550	Resistant	427	392	35	2.763	15:1	0.30-0.20
6	Suraksha x Nagarjuna	Resistant	438	351	87	0.356	13:3	0.99-0.98
7	Suraksha x IET - 14074	Resistant	404	350	53	2.03	57:7	0.50-0.30
8	Suraksha x Chandan	Resistant	248	210	38	0.326	55:9	0.90-0.80
9	Suraksha x ARC 10550	Resistant	361	332	29	1.958	15:1	0.50-0.30
10	IET - 12537 x IET - 14074	Resistant	341	215	126	2.65	43:21	0.30-0.20
11	IET - 12537 x Suraksha	Resistant	265	200	65	5.42	13:3	0.10-0.05
12	IET - 12537 x Chaitanya	Resistant	341	228	113	0.016	43:21	0.99
13	IET - 12537 x ARC - 10550	Resistant	285	227	58	0.478	13:3	0.98-0.95
14	Nagarjuna x IET - 14074	Resistant	333	220	113	0.190	43:21	0.95-0.90
15	Nagarjuna x ARC - 10550	Resistant	421	350	71	0.982	13:3	0.70-0.50
16	MTU - 1001 x Nagarjuna	Resistant	302	249	53	0.286	13:3	0.90-0.80
17	MTU - 1001 x IET - 14074	Resistant	344	308	36	0.079	57:7	0.99-0.98
18	MTU - 1001 x ARC - 10550	Resistant	385	365	2070	0.732	15:1	0.70-0.50
19	Chandan x IET - 12537	Susceptible	407	233	174	0.053	37:27	0.99-0.98
20	Chandan x IET - 8116	Resistant	424	358	66	0.698	55:9	0.80-0.70

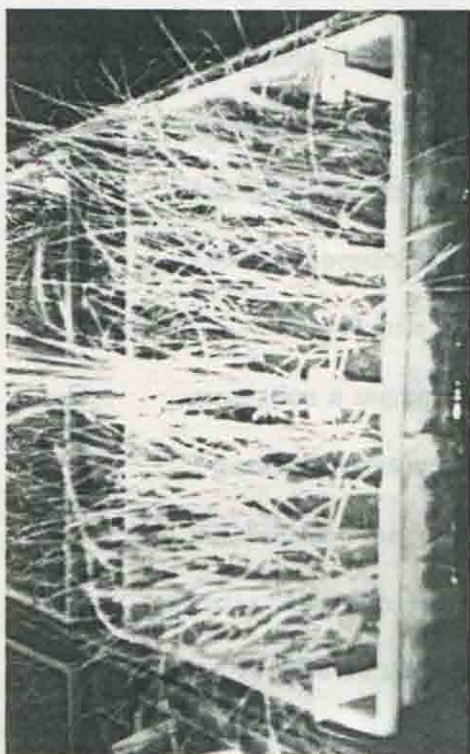


Plate No. 17 Cross-Between Suraksha x Chandan

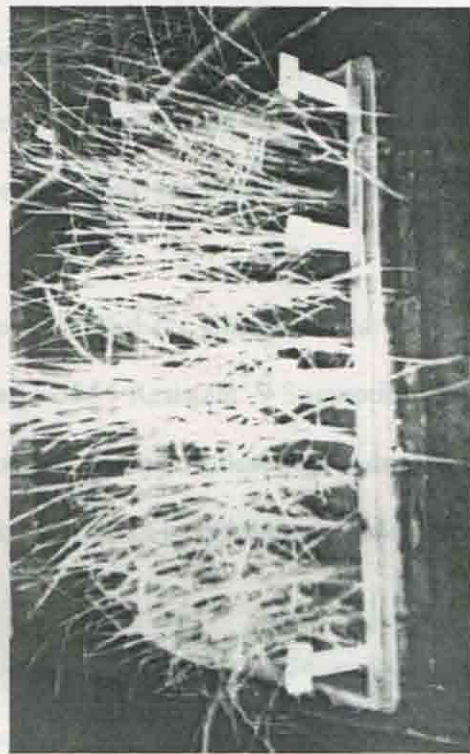


Plate No. 19 Cross-Between IET 12537 x Suraksha

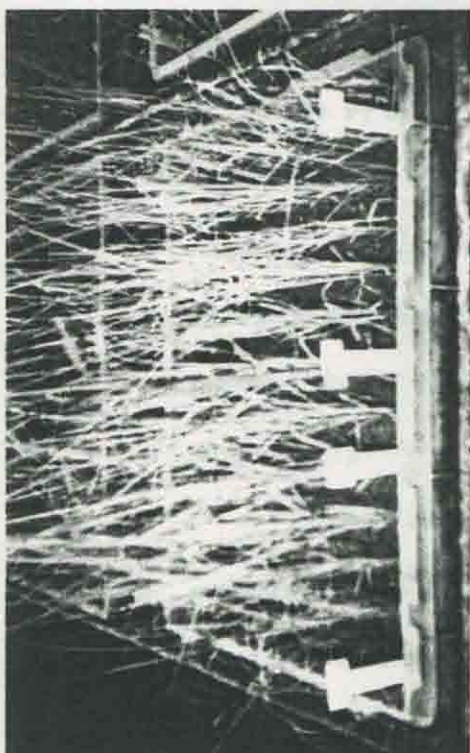


Plate No. 16 Cross-Between Suraksha x IET 14074

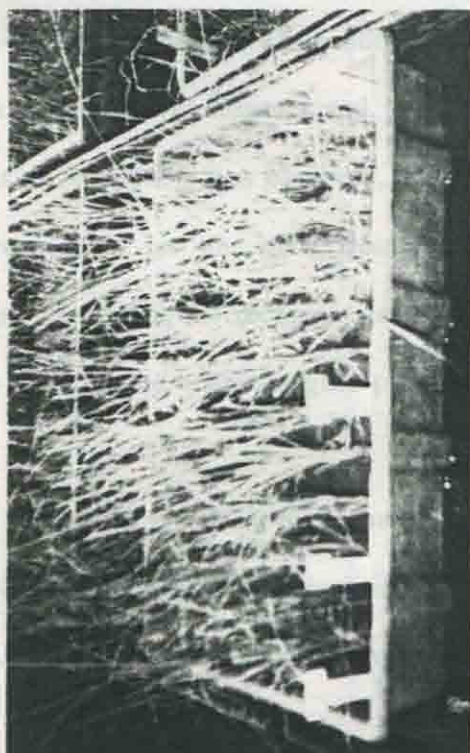


Plate No. 18 Cross-Between IET 12537 x IET 14074

When Suraksha and IET 14074 were crossed, their F_1 's were resistant and a segregation ratio of 57 Resistant: 7 Susceptible plants were observed in F_2 , suggesting that 3 genes were involved in the inheritance of resistance. One of these was a dominant gene present in Suraksha and the other two genes which are dominant and acting in complementation are present in other parent i.e. IET 14074 (Appendix 9).

The F_1 of a cross between Suraksha x Chandan was resistant and in F_2 generation it segregated into a ratio of 55 Resistant: 9 Susceptible, indicating that 3 genes were responsible for resistance. One of these was a dominant gene from Suraksha and the other parent viz., Chandan possessed two independent recessive genes (Appendix 10).

The F_1 's of IET 12537 crossed with IET 14074 and Chaitanya showed resistant reaction and F_2 segregated in a ratio of 43 Resistant: 21 Susceptible indicating that resistance was governed by three non-allelic genes, one of which was a recessive gene of IET 12537 and two dominant complementary genes for resistance were present in IET 14074 and Chaitanya. (Appendix 8)

The F_1 of IET 12537 x Suraksha was resistant and in F_2 generation a segregation ratio of 13 Resistant: 3 Susceptible was observed, indicating that the resistance was governed by two genes i.e. one gene from IET 12537 and additional dominant gene in Suraksha. Thus the recessive gene responsible for resistance in IET 12537 is non-allelic to the dominant gene present in Suraksha (Appendix 5).

The F_1 of cross between Nagarjuna and IET 14074 was resistant and in F_2 generation a ratio of 43 Resistant: 21 Susceptible was obtained, indicating that 3 genes were involved in the inheritance of resistance. One of those was a recessive

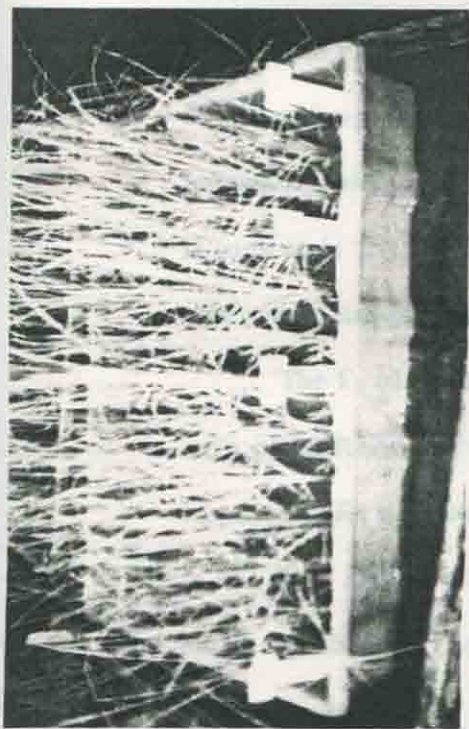


Plate No. 20 Cross-Between Nagarijuna x IET 14074

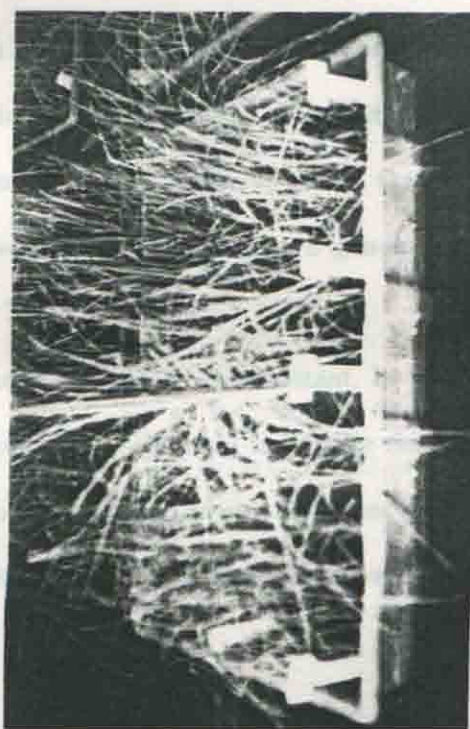


Plate No. 22 Cross-Between MTU 1001 x IET 14074

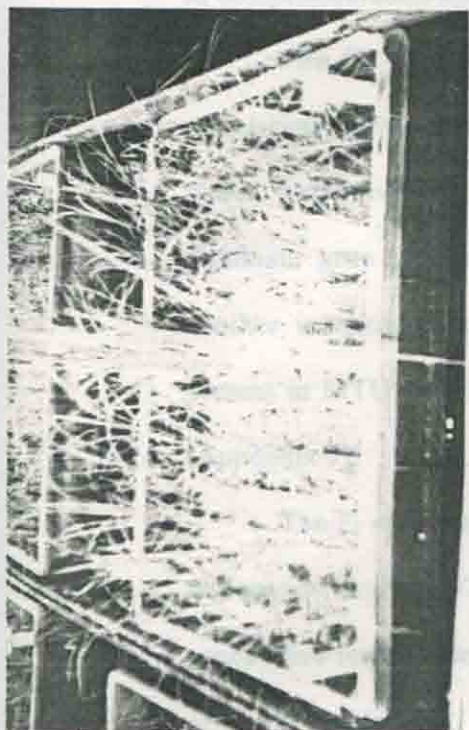


Plate No. 21 Cross-Between MTU 1001 x Nagarijuna

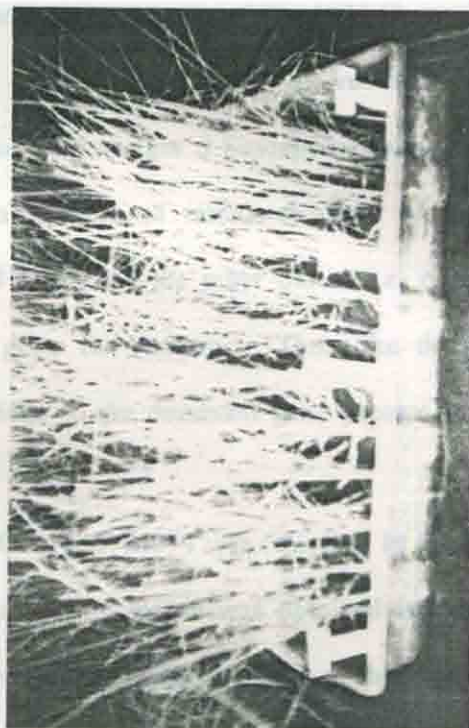


Plate No. 23 Cross-Between Chandra x IET 8116

gene present in Nagarjuna and the other two genes that were dominant and acting in complementation are present in other parent viz., IET 14074 (Appendix 8).

The F_1 of cross MTU 1001 x Nagarjuna was resistant and the F_2 population segregated in a ratio of 13 Resistant: 3 Susceptible indicating that two genes were involved in the inheritance of resistance. One of those was a dominant gene present in MTU 1001 and the other parent i.e. Nagarjuna had another independent recessive gene for resistance. Thus, the dominant gene present in MTU 1001 is non-allelic to the dominant gene present in Nagarjuna (Appendix 5).

The F_1 of cross MTU 1001 x IET 14074 was resistant. In F_2 generation a segregation ratio of 57 Resistant: 7 Susceptible was obtained indicating that 3 genes were responsible for inheritance of resistance. One of these was dominant gene present in MTU 1001 and the other two genes that were dominant and acting in complementation were present in other parent viz., IET 14074 (Appendix 8).

The F_1 of cross between Chandan and IET 12537 was susceptible, but in F_2 generation a segregation ratio of 37 Resistant: 27 Susceptible was observed, indicating that resistance was governed by 3 recessive genes. One recessive gene is present in IET 12537 and two independent recessive genes were present in other viz., Chandan. (Appendix 7).

The F_1 of cross Chandan x IET 8116 was resistant. In F_2 a segregation ratio of 55 Resistant: 9 Susceptible was observed indicating that 3 genes were responsible for the inheritance of resistance. The one dominant gene was present in IET 8116 and the other two independent recessive genes were present in other parent i.e. Chandan. (Appendix 10).

DISCUSSION

CHAPTER V

DISCUSSION

Regular screening for brown planthopper resistance are done in the Department of Entomology. The Entomology department reported varieties ARC 10550, Chandan, Chaitanya, Suraksha, Nagarjuna, MTU 1001, IET 14074, IET 12537, IET 8116, BG 380-2 and Triguna resistant against the mixed population (naturally existing population) of brown planthopper (Personal communication). These were further screened against the existing biotype population at Raipur and their reactions were studied. Varieties IET 12537, IET 14074, Chandan, Nagarjuna and Suraksha were found resistant whereas the IET 8116, Chaitanya, MTU 1001 and ARC 10550 were scored moderately resistant. All these five resistant and four moderately resistant varieties were selected for the present inheritance and allelic studies.

The variable reactions ranging from resistant to susceptible were observed against Raipur brown planthopper population. The population of Raipur is supposed to be a mixture of biotype 1 and biotype 2 (Pophaly *et al.*, 1997). Varying level of resistance were noticed earlier by Murty *et al.* (1988), Sahu and Shrivastava (1989), Pophaly *et al.* (1997) and Pophaly and Rana (1993).

5.1 Mode of inheritance:

Among the resistant and moderately resistant accessions tested against Indian Biotype (the pure population being maintained at DRR, Hyderabad), 9 accessions were selected to study the mode of inheritance of resistance conferring genes. These were ARC 10550, Chandan, IET 8116, IET 12537, IET 14074,

Chaitanya, MTU 1001, Nagarjuna and Suraksha. Chandan and IET 12537 were crossed with a known susceptible check TN 1. Since TN 1 is early variety and resistant varieties were late maturing, therefore all the crosses could not be attempted with TN 1 and some crosses were made with Swarna. MTU 1001, Chaitanya, Nagarjuna, Suraksha and IET 14074 were crossed with another known susceptible variety Swarna. ARC 10550 and IET 8116 were crossed with both TN 1 and Swarna. The insect population was not sufficient at Raipur for screening and no pure biotype is being maintained at Raipur, therefore for the study of inheritance and allelic tests, the F_1 's and F_2 's were screened at Directorate of Rice Research, Hyderabad where pure Indian biotype is being maintained.

The F_1 's of TN 1 with ARC 10550 and IET 8116 and those of Swarna with ARC 10550, MTU 1001, IET 8116 and Suraksha were resistant, indicating that the resistance was dominant over susceptibility. The proportion of resistant and susceptible seedlings in the F_2 generation of these crosses agreed with the ratio of 3 resistant: 1 susceptible plants, segregation for single dominant gene. Several similar results were reported earlier by Laxminarayan and Khush (1977), Ikeda and Kenada (1985), Anwarul Kabir and Khush (1988) and Tomar and Prasad (1996).

The F_1 hybrids of TN 1 with IET 12537 and Swarna with Nagarjuna were susceptible, indicating that the resistance was due to recessive genes. The ratio of resistant and susceptible seedlings in the F_2 populations of these crosses was most fitted with the ratio of 1 resistant: 3 susceptible. The monogenic recessive nature of resistance against brown planthopper was also reported earlier by

Lakshminarayana and Khush (1977), Prasada Rao *et al.* (1977), Ikeda and Kenada (1985), Angeles *et al.* (1985), Anwarul Kabir and Khush (1988) and Tomar and Prasad (1996).

The F_1 and F_2 reactions of the crosses TN 1 x Chandan indicated that resistance in Chandan variety was conferred due to two recessive genes, whereas resistance in Chaitanya and IET 14074 was due to two complementary dominant genes.

The varieties under study have either one or two genes responsible for resistance, whereas more than two genes for resistance were reported earlier by several workers viz., three-gene control was reported by Ikeda and Kenada (1985) and Tomar and Prasad (1996). Martinez and Khush (1974) reported the inhibitory nature of resistance. The polygenic nature of resistance was also reported by Xu XiaoFeng *et al.* (1999).

The resistant gene in the variety ARC 10550 was earlier reported to be recessive i.e. *bph5* (Anwarul Kabir and Khush, 1988), but in this study it was observed to be dominant. Also the findings of Directorate of Rice Research, Hyderabad confirmed it to be dominant and allelic to *Bph6*. (Anonymous 2000)

The resistance controlled by major genes as observed in the present study is more desirable for their utilization in breeding programmes, since their incorporation is relatively simple.

5.2 Allelic tests:

The F_1 hybrids of crosses of IET 8116 x IET 12537, Suraksha x Nagarjuna, IET 12537 x Suraksha, IET 12537 x ARC 10550, Nagarjuna x ARC 10550 and MTU 1001 x Nagarjuna were resistant. In the F_2 generation a

segregation ratio of 13 resistant: 3 susceptible was observed, indicating that resistance is governed by two genes i.e. one dominant gene present in ARC 10550, IET 8116 and Suraksha, and a recessive gene present in IET 12537 and Nagarjuna which are non-allelic. Lakshminarayana and Khush (1977), Prasada Rao et al. (1977), Angeles et al. (1985) observed the similar results, Ikeda and Kenada (1985) and Tomar and Prasad (1996).

The F_1 's of crosses IET 8116 x ARC 10550, IET 8116 x Suraksha, Suraksha x ARC 10550 and MTU 1001 x ARC 10550 were resistant. The proportion of resistant to susceptible seedlings in the F_2 generation was 15 resistant: 1 susceptible respectively expected on the basis of independent segregation of two dominant genes. These results were in conformity with the results observed by Lakshminarayana and Khush (1977), Ikeda and Kenada (1985) and Tomar and Prasad (1996).

The F_1 of cross between Chandan and IET 12537 was susceptible, and the F_2 generation segregated in the ratio of 37 resistant: 27 susceptible, indicating that 3 recessive genes governed the resistance. This ratio could be due to one recessive gene present in Chandan and two complementary dominant genes present in IET 12537.

The F_1 's of crosses of Nagarjuna with IET 14074, IET 12537 with IET 14074 and Chaitanya were all resistant. The F_2 of these crosses segregated in the ratio of 43 resistant: 21 susceptible, indicating the presence of at least three genes conferring the resistance. This ratio could be due to one recessive gene present in Nagarjuna and IET 12537, and IET 14074 and Chaitanya seemed to possess two complementary dominant genes.

The F_1 plants of IET 8116 x IET 14074, Suraksha x IET 14074 and MTU 1001 x IET 14074 were resistant and in F_2 a segregation ratio of 57 resistant: 7 susceptible, was observed indicating a trigenic nature of resistance. This ratio could be attributed to the presence of one dominant gene in IET 8116, MTU 1001 and Suraksha, and two complementary dominant genes in IET 14074.

The F_1 's of Suraksha x Chandan, IET 8116 x Chandan and reciprocal cross Chandan x IET 8116 and Suraksha x Chandan were all resistant and in F_2 's these crosses segregated in a expected ratio of 55 resistant: 9 susceptible. This ratio could result from the segregation of one dominant and two recessive genes. The one dominant gene was present in IET 8116 and Suraksha, and two independent recessive genes were present in Chandan for resistance and these results are in agreement with those of results observed by Ikeda and Kaneda (1985) and Tomar and Prasad (1996).

The allelic study thus revealed that resistant gene present in IET 8116 was different, other than the resistant gene present in IET 12537, Suraksha and ARC 10550. Similarly the resistant genes present in Suraksha were different from the resistant genes present in Nagarjuna, IET 14074, Chaitanya and ARC 10550, and the resistant gene present in IET 14074, Suraksha, Chaitanya and ARC 10550. The resistant genes present in Nagarjuna and IET 14074 are also non-allelic to each other. The resistant genes present in MTU 1001 were non-allelic to the resistant genes present in Nagarjuna and ARC 10550. The resistant genes present in Chandan are non-allelic to IET 12537 and IET 8116. The resistant genes present in the genotypes under study should be incorporated in the breeding lines to develop the diverse sources of resistance. The dominant genes identified in

varieties viz., IET 8116, ARC 10550, MTU 1001, Suraksha, IET 14074 and Chaitanya may be utilized in hybrid rice breeding programme also. The diverse sources of resistance as identified in the present study would prove to be promising to combat the brown planthopper menace and stable resistance would be obtained. The inheritance nature is simple; therefore pedigree breeding method or backcross breeding method can be followed to incorporate these resistant genes in to improved breeding lines. In the present age of biotechnology, the identification of independent (non-allelic) genes would be helpful in pyramiding the resistant genes to develop stable resistance.

*SUMMARY, CONCLUSIONS AND
SUGGESTIONS FOR FUTURE WORK*

CHAPTER VI

SUMAMRY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

“Genetic Analysis of Resistance to Brown Planthopper, *Nilaparvata lugens* (Stål) in Some Selected Rice Varieties” was conducted during *Kharif* 2000 to *Kharif* 2001 in the Department Of Plant Breeding and Grenetics, Indira Gandhi Agricultural University, Raipur (C.G.) with following objectives.

1. Rescreening of 11 resistant varieties against Raipur population of brown planthopper, *Nilaparvata lugens* (Stål).
2. To study the mode of inheritance of resistance operating in selected resistant genotypes against standard Indian biotype of *Nilaparvata lugens* (Stål).
3. To study allelic relationship of resistant genes in these cultivars.

Eleven rice varieties earlier reported as resistant through screening at Raipur against the Raipur population of brown planthopper were further screened. Out of these, IET 12537, IET 14074, Chandan, Nagarjuna and Suraksha were found to be resistant. Genotypes IET 8116, Chaitanya, MTU 1001 and ARC 10550 were scored as moderately resistant.

The mode of inheritance was studied in varieties *viz.*, ARC 10550, Chandan, IET 8116, IET 12537, MTU 1001, Chaitanya, Nagarjuna, Suraksha and IET 14074. These were crossed with susceptible varieties. On the basis of screening results four varieties *viz.*, ARC 10550, Chandan, IET 8116 and IET 12537 were crossed with TN

1 and ARC 10550, MTU 1001, Chaitanya, Nagarjuna, IET 8116, Suraksha, IET 14074 were crossed with Swarna. The insect reactions of these crosses in F_1 and F_2 generations were analysed for inheritance study for brown planthopper resistance.

F_1 progenies of the crosses of TN 1 with ARC 10550 and IET 8116 and those of Swarna with ARC 10550, MTU 1001, IET 8116 and Suraksha were resistant, indicating that the resistance was dominant over susceptibility. These crosses in F_2 generation segregated in the ratio of 3 Resistant: 1 Susceptible, indicating that a single dominant gene governed the resistance in ARC 10550, IET 8116, MTU 1001 and Suraksha.

The F_1 's of Swarna with Nagarjuna, TN1 with IET 12537 were susceptible, indicating the recessive nature of resistance and in F_2 a ratio of 1 resistant: 3 susceptible was observed which indicated that resistance in Nagarjuna and IET12537 was conferred by a single recessive gene.

The F_1 plants of the cross between TN 1 and Chandan were susceptible, indicating the recessive nature of resistance. The F_2 population segregated into a ratio of 7 resistant: 9 susceptible. This was due to two independent recessive genes present in Chandan.

The F_1 's from crosses Swarna and Chaitanya and Swarna and IET 14074 were all resistant and the F_2 plants segregated into a good fit ratio of 9 resistant: 7 susceptible. This was due to presence of two complementary dominant genes present in Chaitanya and IET 14074.

Crosses among resistant x resistant genotypes segregated independently thus indicating the presence of non-allelic genes in the genotypes under study.

Suggestions for future work:

1. The resistant accessions, identified through various genetical studies should further be tested against the other International differentials, so that the new resistant genes may be designated.
2. The recessive genes present in the varieties should further be tested for allelic relationship among themselves, so that the non-allelic genes can be differentiated for the selection of donor parents.
3. The recessive nature of gene(s) governing resistance observed in the present study should be tested further for allelic test against the known recessive gene(s) like *bph2* and *bph4*.
4. The identified resistant lines against Indian biotype (Hyderabad) should be tested against other prevalent biotypes of the region to identify the genotypes possessing resistance for local biotype.
5. Selected resistant accessions should be crossed in all possible combinations to determine their allelic relationship or with differentials for allelic tests.
6. The expected ratios observed in F_2 should further be tested in F_3 to confirm the F_2 's results.

ABSTRACT

**Genetic Analysis of Resistance to Brown Planthopper,
Nilaparvata lugens (Stål) in Some Selected Rice Varieties**

by

Umate Sunil Marotirao

ABSTRACT

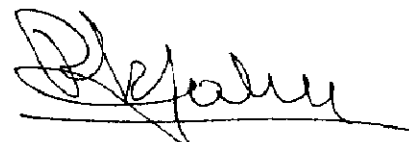
The inheritance and allelism of genes for resistance to brown planthopper, *Nilaparvata lugens* (Stål) in eleven resistant rice varieties were studied. Two leaf stage seedlings were artificially infested in the screen house with second and third instar brown planthopper nymphs, using standard seed box technique. Reactions of the seedlings were recorded seven to ten days after infestation, by them the susceptible check, TN 1, was completely killed. While screening, out of eleven varieties under study two viz., Triguna and BG 380-2 were found susceptible, therefore genetical studies were made on nine varieties only.

Mode of inheritance was studied by crossing resistant varieties with susceptibles. Their F_1 and F_2 populations revealed that a single dominant gene governed the resistance in IET 8116, MTU 1001, Suraksha, and ARC 10550. Whereas a single recessive gene controlled resistance in IET 12537 and Nagarjuna. Chandan possess two recessive genes whereas Chaitanya and IET 14074 possess two complementary dominant genes.

The allelic study thus revealed that resistant gene present in IET 8116 was different, other than the resistant gene present in IET 12537, Suraksha and ARC 10550. Similarly the resistant genes present in Suraksha were different from the resistant genes present in Nagarjuna, IET 14074, Chaitanya and ARC 10550, and the resistant gene present in IET 14074, Suraksha, Chaitanya and ARC 10550. The resistant genes present in Nagarjuna and IET 14074 are also non-allelic to

each other. The resistant genes present in MTU 1001 were non-allelic to the resistant genes present in Nagarjuna and ARC 10550. The resistant genes present in Chandan are non-allelic to IET 12537 and IET 8116. The resistant genes present in the genotypes under study should be incorporated in the breeding lines to develop the diverse sources of resistance. The dominant genes identified in varieties viz., IET 8116, ARC 10550, MTU 1001, Suraksha, IET 14074 and Chaitanya may be utilized in hybrid rice breeding programme also.

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APPENDIX

Appendix :

1. Genotypes of parents showing 3 R : 1 S phenotypic ratio in F_2 having one dominant gene for resistance.

Parents Genotypes	Susceptible Aa	X	Resistant AA
F_1		Aa	(Resistant)
F_2	Genotype	Frequency	Phenotype
1	AA	1	R
2	Aa	2	R
3	Aa	1	S

Phenotypic Ratio 3 R : 1 S

Assumption: " A " in either homozygous or heterozygous condition imparts resistance and presence of homozygous recessive gene (aa) leads to susceptibility.

2. Genotypes of parents showing 1 R : 3 S phenotypic ratio in F_2 having one recessive gene for resistance.

Parents Genotypes	Susceptible bb	X	Resistant BB
F_1		Bb	(Resistant)
F_2	Genotype	Frequency	Phenotype
1	BB	1	S
2	Bb	2	S
3	bb	1	R

Phenotypic Ratio 1 R : 3 S

Assumption: " b " in homozygous condition (bb) imparts resistance whereas presence of " B " in either homozygous or in heterozygous condition leads to susceptibility.

3. Genotypes of parents showing 7 R : 9 S phenotypic ratio in F_2 having two genes for resistance.

Parents Genotypes	Susceptible AABB (-----)	X	Resistant aabb (-----)
F_1		AaBb	(Resistant)
F_2	Genotype	Frequency	Phenotype
1	AAbb	1	R
2	Aabb	2	R
3	aaBB	1	R
4	aaBb	2	R
5	aabb	1	R
6	AABB	1	S
7	AABb	2	S
8	AaBB	2	S
9	AaBb	4	S

Phenotypic Ratio 7 R : 9 S

Assumption : Either " a " or " b " in homozygous condition imparts resistance whereas presence of both dominant genes leads to susceptibility.

4. Genotypes of parents showing 9 R : 7 S phenotypic ratio in F_2 having two dominant genes in complementation for resistance.

Parents Genotypes	Susceptible aabb (----- -)	X	Resistant AABB (-----)
F_1		AaBb	(Resistant)
F_2	Genotype	Frequency	Phenotype
1	AABB	1	R
2	AABb	2	R
3	AaBB	2	R
4	AaBb	4	R
5	Aabb	1	
6	Aabb	2	S
7	aaBB	1	S
8	aaBb	2	S
9	aabb	1	S

Phenotypic Ratio 9 R : 7 S

Assumption: Both " A " and " B " in complementation imparts resistance whereas presence of either " a " or " b " in homozygous condition leads to susceptibility.

5. Genotypes of parents showing 13 R : 3 S phenotypic ratio in F_2 having one recessive and one dominant gene for resistance.

Parents Genotypes	Resistant AABB	X	Resistant aabb
F_1		AaBb	Resistant
F_2	Genotype	Frequency	Phenotype
1	AABB	1	R
2	AABb	2	R
3	AAbb	1	R
4	AaBB	2	R
5	AaBb	4	R
6	Aabb	2	R
7	aabb	1	R
8	aaBb	2	S
9	aaBB	1	S

Phenotypic Ratio **13 R : 3 S**

Assumption: Resistance in one parent is imparted by one dominant gene "A" and in other parent it was controlled by one recessive gene "b". Presence of "A" gene in homozygous recessive (aa) and dominant homozygous (BB) and / or heterozygous (Bb) leads to the susceptibility.

6. Genotypes of parents showing 15 R : 1 S phenotypic ratio in F_2 having two independent dominant genes for resistance.

Parents Genotypes	Resistant AAbb	X	Resistant aaBB
F_1		AaBb	Resistant
F_2	Genotype	Frequency	Phenotype
1	AABB	1	R
2	AABb	2	R
3	AAbb	1	R
4	AaBB	2	R
5	AaBb	4	R
6	Aabb	2	R
7	aaBB	1	R
8	aaBb	2	R
9	aabb	1	S

Phenotypic Ratio 15 R : 1 S

Assumption: Resistance in one parent is imparted by one dominant gene " A " and in another parent it was controlled by dominant gene " B ", whereas presence of both " a " and " b " recessive genes in homozygous could have leads to susceptibility.

7. Genotypes of parents showing 43 R ; 21 S phenotypic ratio in F_2 having one recessive gene and two complementary dominant genes for resistance.

Parents Genotypes	Resistant aabbcc	X	Resistant AABBCC
F_1		AaBbCc	Resistant
F_2	Genotype	Frequency	Phenotype
1	A - B - C -	27	Resistant
2	A - B - cc	9	Susceptible
3	A - bb C -	9	Susceptible
4	aa B - C -	9	Resistant
5	A - bb cc	3	Susceptible
6	aa B - cc	3	Resistant
7	aa bb C -	3	Resistant
8	aa bb cc	1	Resistant

Phenotypic Ratio : 43 R : 21 S

Assumption: Resistance in one parent is imparted by the homozygous recessive gene "a" and in another parent it is controlled by two complementary dominant genes "B" and "C". Presence of dominant homozygous (AA) or heterozygous (Aa) and recessive homozygous "b" (bb) and / or recessive homozygous "c" (cc) leads to susceptibility.

8. Genotypes of parents showing 55 R ; 9 S phenotypic ratio in F_2 having one dominant gene and two recessive genes for resistance.

Parents Genotypes	Resistant AABBCC	X	Resistant Aabbcc
F_1		AaBbCc	Resistant
F_2	Genotype	Frequency	Phenotype
1	A - B - C -	27	Resistant
2	A - B - cc	9	Resistant
3	A - bb C -	9	Resistant
4	aa B - C -	9	Susceptible
5	Aa bb cc	3	Resistant
6	aa B - cc	3	Resistant
7	aa bb C -	3	Resistant
8	aa bb cc	1	Resistant

Phenotypic Ratio : 55 R : 9 S

Assumption: Resistance in one parent is imparted by the dominant gene "A" and in other parent it was controlled by two independent recessive genes "b" and "c". Presence of recessive homozygous "a" (aa) and dominant homozygous (BB or CC) and / or heterozygous (Bb or Cc) leads to susceptibility.

9. Genotypes of parents showing 57 R : 7 S phenotypic ratio in F_2 having one independent dominant gene and two complementary dominant genes for resistance.

Parents Genotypes	Resistant AAbbcc	X	Resistant AaBBCC
F_1		AaBbCc	Resistant
F_2	Genotype	Frequency	Phenotype
1	A - B - C -	27	Resistant
2	A - B - cc	9	Resistant
3	A - bb - C -	9	Resistant
4	aa B - C -	9	Resistant
5	Aa bb cc	3	Resistant
6	aa B - cc	3	Susceptible
7	aa bb C -	3	Susceptible
8	aa bb cc	1	Susceptible

Phenotypic Ratio : 57 R : 7 S

Assumption: Resistance in one parent is imparted by the dominant gene "A" and in other parent it was controlled by two complementary genes "B" and "C". Presence of recessive homozygous "a" (aa) along with recessive homozygous "b" (bb) and / or recessive homozygous "c" (cc) leads to susceptibility.

10. Genotypes of parents showing 37 R : 27 S phenotypic ratio in F_2 having three independent recessive genes for resistance.

Parents Genotypes	Resistant aabbcc	X	Resistant AABBcc
F_1		AaBbCc	Resistant
F_2	Genotype	Frequency	Phenotype
1	A - B - C -	27	Susceptible
2	A - B - cc	9	Resistant
3	A - bb - C -	9	Resistant
4	aa B - C -	9	Resistant
5	Aa bb cc	3	Resistant
6	aa B - cc	3	Resistant
7	aa bb C -	3	Resistant
8	aa bb cc	1	Resistant

Phenotypic Ratio : 57 R : 7 S

Assumption: The resistance is conferred due to three independent recessive genes.

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