GENETIC ANALYSIS OF BROWN PLANTHOPPER RESISTANCE IN RICE

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DECLARATION

I hereby declare that this thesis entitled "Genetic analysis of Brown Planthopper resistance in rice" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Genetic analysis of Brown Planthopper resistance in rice" is a record of research work done independently by Smt. N. Rema Bai, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

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The Brown planthopper, Nilaparvata lugens (Stal) has caused extensive damage to the rice crop in Asia. Although an important pest in Japan for many years, it was known only as a minor pest in most tropical Countries of Asia in the past. However, the BPH populations have greatly increased in the recent past and has caused substantial crop losses in several Asian Countries such as India, Indonesia, the Philippines and Sri Lanka. Infestations of varying degrees are now commonly observed in these countries and consequently BPH is now regarded as a major pest of rice in Asia.

The most severe outbreak of BPH in India occurred in Kerala in late 1973 and early 1974. (Nalinakumary and Mammen, 1975). Eventhough the pest was recorded during 1958 and 1962, the outbreak in 1973-74 was the first major one in Kerala in the 'Kole' lands and the 'Kuttanad' area (Dyck and Thomas, 1979) resulting in economic damage in about 50,000 ha of rice. About 8000 ha was almost completely wiped out (Gopalan, 1974). Hopperburn frequently developed in patches and sometimes covered whole fields (Kulshreshtha, 1974) (Figure 1). In many fields, the

Figure 1

Crop showing hopperburn

FIGURE. 1.

damage was so great that the farmers had abandoned the crop (Das et al., 1972). The losses in grain yield ranged from 10 to 70% (Kulshreshtha et al., 1974), at times reaching 100%. BPH has become a damaging pest in as many as 10 states of India including Uttar Pradesh, Bihar, Haryana and Punjab (Kalode, 1976). Chelliah and Subramanian (1972-73) mentioned that BPH occurs in epidemic form and causes extensive damage once every few years in Tamil Nadu. When the pest density is high, the plant dies and a condition known as hopperburn results (Dyck and Thomas, 1979). Natarajan et al. (1988) stated that during the 1987 drought due to failure of the monsoon, a BPH outbreak in Thanjavur District, caused typical hopper burn symptoms in IR 50. The insect may also transmit grassy stunt virus which can further reduce yield.

Although timely application of insecticides provides effective control, large scale chemical control is difficult and expensive. Repeated sprayings upset the natural balance between the insect and its natural enemies and also cause environmental pollution (Kalode and Krishna, 1979). The logical approach to BPH control would therefore be the use of host plant resistance. In recent years, resistant varieties have received increasing attention because of the

growing awareness of the shortcomings of chemical pesticides. In pest management, plant resistance thus forms an important component on which several other methods of pest suppression can be superimposed with a high degree of complementarity (Chelliah, 1986). Until recently the BPH resistant variety IR 26 was thought to be a simplistic solution for the BPH problem. But when IR 26 was found to be susceptible in India, the presence of a different biotype from that available in the Philippines was inferred (Brady, 1979). Three years after its release, IR 26 became susceptible in the Philippines also, indicating a change in biotype. A major difference between the insect populations in South Asia and those in the rest of Asia is evident indication of biotype differences. Differential reactions within areas in India have also been reported (Seshu and Kauffman, 1980).

It is important that the available germplasm be screened to locate resistance and to incorporate resistance with other desirable plant characters into new varieties. The identification of a large number of cultivars with BPH resistance along with the characterization of their genotype is thus desirable (Ikeda and Kaneda, 1986). Genetic resistance in crop plants can be more effectively utilized

with a sound knowledge on the mechanisms of resistance and the sources of resistance (Chelliah, 1986). A study of the mechanism of BPH resistance makes possible the incorporation of the more desirable antibiosis type resistance into improved varieties.

Large scale cultivation of resistant varieties can lead to the build up of new biotypes, to which the old varieties succumb. Sequential release of resistant varieties with resistance to newly emerging biotypes is therefore quite essential. Incorporating diverse genes in various combinations would ensure stability of resistance. A thorough and clear understanding of the mode of inheritance of resistance is essential for the identification of resistant donor varieties and to locate diverse genes for resistance.

A number of breeding lines and varieties with resistance to BPH have already been developed. Several donors have also been identified from South east Asia especially from Kerala. But a detailed analysis of the genetic basis of BPH resistance to locate more donors and their resistance has not yet been attempted in this region. The present work was therefore undertaken to screen rice

varieties against BPH to locate sources of resistance and to understand the mode of inheritance of BPH resistance. Such basic information will enable the development of new resistant varieties with a broad spectrum of resistance to local and other biotypes of the insect.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

1. Sources of BPH resistance

Gunavardena et al. (1975) studied the resistance of 1000 rice varieties to BPH in Sri Lanka and reported that the varieties Suduheenati, Heenrathkunda, Sudurusamba and Mawee were highly resistant. Kudagamage (1976) evaluated 500 indigenous varieties and foreign introductions in the greenhouse in Sri Lanka for resistance to BPH and recorded that varieties Ptb 33, ARC 6650, Sudurusamba, MR 1523 and Suduheenati were the highly resistant lines.

In Philippines, Seshu and Kauffman (1980) have reported the results of an international screening programme involving rice and BPH carried out in several countries of Asia. The results provide significant information on biotype variation in BPH and sources of genetic resistance to the different biotypes in the various countries. Ptb 33, Sudurusamba and Sinna Sivappu were resistant at almost all test sites. Several improved breeding lines derived from Ptb 33 were promising in all the regions of Asia and Solomon Islands.

Mugiano et al. (1984) tested seven mutant lines in Philippines. These lines were derived from susceptible

Pelita 1/1 at IRRI. The lines were resistant to moderately resistant to BPH biotype 1 and 3 but susceptible to biotype 2.

Heinrichs et al. (1985) evaluated IR varieties for resistance to 15 insect pest species in the greenhouse, screenhouse and fields in Philippines. According to them, recently recommended IR varieties were resistant to biotypes 1, 2 and 3 of BPH.

At IRRI, many varieties and lines were recorded as resistant to different biotypes of the BPH in 1977. Twelve elite breeding lines were identified as resistant or moderately resistant to three biotypes. Each line had CR 94-13 as a parent. Of the 118 varieties that had been identified as resistant to BPH at AICRIP, only 52 were resistant to all the three biotypes, 10 were resistant to biotype 1 and 2 and 42 were susceptible to 3 biotypes indicating that the biotype at Hyderabad is different from the biotypes at IRRI (IRRI, 1978).

Nine hundred and fourteen cultivars from North east India were evaluated for BPH resistance by Kalode and Krishna (1979). Sixtynine were found to be resistant or moderately resistant in replicated tests. About 15 varieties

showed a high level of resistance. The distribution of resistant cultivars from North east India showed that most of them had been derived from the hilly tracts of Assam, Meghalaya and Manipur.

Of 663 cultivars from IRRI, 73 exhibited varying degrees of resistance. 29 showed a high level of resistance. They were earlier found to be resistant or moderately resistant to biotype 1 at IRRI (Kalode and Krishna, 1979).

About 301 entries from Pattambi, and 514 from Coimbatore were evaluated. 96 entries from Coimbatore and 37 from Pattambi had damage scores under 3 in preliminary tests. Of those, 30 from Pattambi and 24 from Coimbatore had scores ranging from 0-1.5. The reactions of entries from Pattambi have been confirmed in replicated tests (Kalode and Krishna, 1979).

A total of 567 traditional tall varieties from the AICRIP collection and the 44 from the APAU collection were also tested. Seven from the AICRIP collection and one from APAU were resistant (Kalode and Krishna, 1979).

Screening of entries in the greenhouse at CRRI revealed BPH resistance in the cultivars Ptb 33, Ptb 21,

Ptb 10, TKM 6, Murungakayan, ARC 5984, ARC 7239, ARC 18529, ARC 14729, ARC 14736, ARC 15223, ARC 15264, ARC 15821, ARC 12627, ARC 15284, ARC 14766, ARC 14529, ARC 10176, AC 131, AC 199, AC 357, AC 1224, AC 1619, AC 3070 and MNP 76 (Kalode and Krishna, 1979).

In Kerala, Thomas (1976) evaluated the resistance of 11 varieties to BPH and found that Ptb 19, Ptb 33 and ARC 6650 were resistant.

When resistance of 10320 varieties and cultures of rice was evaluated in greenhouse, Kalode et al. (1977) found that Ptb 33, T 1432, LuaNgu, Ptb 19, ARC 5839, ARC 7327, Nyane Tee, RP 31-49-2 x Lab Mue Nang and Vijaya x Ptb 19 were the highly resistant lines. Nair et al. (1978) recorded that the rice culture M_{11}-57-5-1 evolved from the cross IR 8 x Ptb 20 was highly resistant. About 15000 rice cultivars were screened by Kalode and Krishna (1979). They identified several resistant and tolerant lines. Materials from North-Eastern India and Kerala were promising for BPH resistance. Krishna et al. (1980) have screened rice varieties and presented a list of 66 tall traditional varieties mostly from India, Viet Nam and Sri Lanka to be resistant or moderately resistant to BPH. They have further tested 140 varieties that were found to be highly resistant to

BPH in greenhouse tests. These varieties included many from India and some from Indonesia, Sri Lanka, Korea, Viet Nam and Laos. Natarajan and Chandy (1980) tested 204 rice cultivars for BPH resistance. They reported that no cultivar was immune to attack, but some showed a certain degree of resistance. About 1070 varieties have been screened by Reddy and Kalode (1981) for resistance, out of which 18 showed resistance. Of these, ARC 5780, ARC 5973 and ARC 12864 had least damage. Das et al. (1984) have tested 12 rice varieties from IRRI and found that IR 13429-196-1-20 and IR 17525-56-22-2 were promising because of their high yield potential and resistance. Resistance was derived from Ptb 33 in both these lines. Seedlings of 465 accessions were evaluated by Veluswamy and Chelliah (1984) for resistance in the greenhouse. 31 varieties were rated as highly resistant and 100 as resistant. Rao and Padhi (1986) evaluated 45 entries for resistance to BPH by bulk seedling method of which seven entries were resistant. Gubbaiah and Vidyachandra (1985) screened 47 rices for field resistance to BPH in 1982 and the promising lines were again screened during 1983. IET 7575 (Sona x Manoharsali) was resistant to BPH. Bhagavandas et al. (1985) identified BPHR-5 (IR 13427-45-2) as having BPH

resistance and good yield potential in Pondichery. This variety is obtained from a multiple cross of IR 3403-267, IR 36 and Ptb 33. Rao (1985) evaluated, 10 known resistant cultures, IR 36 and susceptible Ratna under artificial hopper burn and found that CR 401-7, CR 233-10, CR 157-1900 and CR 157-380-303 were outstandingly superior to IR 36 in field resistance to BPH.

Chelliah (1986) has reported that resistance in rice cultivars to planthopper and leafhopper so far is due to major genes. Vertical resistant sources, particularly in the context of development of biotypes of rice hoppers, emphasizes the need to identify sources of resistance with polygenes. Sustained efforts should lead to the identification of such sources that will have extended commercial life when incorporated into acceptable rice varieties.

Rao (1986) reported that part of the nearly 20,000 rice germplasm accession available at CRRI, Cuttak was systematically evaluated in 1975-80 using BPH first instar nymphs mass reared in the greenhouse. About 700 CRRI accessions, 350 Assam rice collections, 50 Manipur rice collections, 50 Jaipur botanical survey collections, and 100 others were screened using the bulk seedling screening

technique. Of 1,250 rices screened, 59 cultivars and 15 cultures were resistant.

Veluswamy (1987) screened 30 wild rice accessions originating in South and South east Asia and South America for resistance to BPH in the greenhouse at IRRI. All of them were found to be resistant. Wild rices O. latifolia, O. officinalis and O. punctata also were found to be resistant to BPH biotypes 1, 2 and 3.

Sahu (1987) screened 185 rice accessions from Madhya Pradesh (India) germplasm collection at IRRI for resistance to BPH using standard seed box screening technique, of which 3 were resistant. They were Aolesar, Jhili, and Banda. Fifteen types were found to be moderately resistant.

Dhal and Panda (1987) evaluated field resistance to BPH of 13 cultivars, including Jaya and Ratna as susceptible checks in Orissa, India. The BPH population did not exceed 8 individuals/hill until 60 days after transplanting. At 90 DT, susceptible Ratna and Jaya had 218 and 112 BPH/hill. OR 158-13-1 was highly susceptible with 198 BPH/hill. OR 131-11 and OR 131-13-13 had only 7.7 and 11.3 BPH/hill and yielded more than 4 t/ha.

Rajendran et al. (1987) evaluated seven upland rice varieties for resistance to BPH, WBPH and LF in greenhouse at TNAU, India. PM 5845 and PM 1409 showed good levels of BPH and WBPH resistance and moderate levels of LF resistance. PM 1004 was resistant to WBPH and moderately resistant to BPH.

From mass screening of 1268 entries from germplasm, BPHRVT and Punjab material in the greenhouse 54 promising lines were identified at AICRIP, India. Ten entries from BPHRVT viz. IET Nos. 9380, 9704, 9706, 9717, 9725, 10294, 10300, 10301, 10303 and 1309 exhibited low damage. Two entries viz., 3644 SafedDanwar and K 2351 Kabari were promising among the 1145 entries evaluated from Rajpur germplasm. The most promising advanced breeding lines were from RP 239, RP 2042, RP 2343, RP 2347, RP 2351, RP 2355, RP 2359, RP 2360, RP 2362, RP 2365, RP 2361, RP 2363 and RP 2368 (DRR, 1987).

From field plot tests in 3 areas of Java and Indonesia, Mochida et al. (1976) recorded that rice varieties IR 26, IR 28 and IR 30 were resistant to BPH. Ptb 19, Ptb 33 and ARC 6650 were also found to be resistant.

Lee and Je-Yuntian (1984) in China screened 313 varieties

for BPH resistance and found that 37 were resistant at seedling stage and 53 showed field resistance. Among the resistant varieties were cultivars from India, Sri Lanka, Indonesia, Thailand, IRRI, Taiwan, China, Japan, Burma, Malaya, Malagasy and Pakistan.

Kabir and Alum (1981) in Solomon Islands recorded that 10 out of the 450 varieties screened were highly resistant and 27 were resistant.

Dong and Taro (1985) studied the resistance of rice cultivar BG 379-5 (BG 96-3/Ptb 33) in the 1980 IRBPHN in Bengladesh and found that it was highly resistant. This line is belived to possess the Ptb 33 resistance gene.

Choi (1980) in Korea have pointed out that although a large number of resistant varieties exist, varieties that are resistant in one country are not necessarily resistant in the other countries.

2. Screening for resistance

According to Fernando et al. (1979) in Sri Lanka, two characteristics that emerge from seedling screening for BPH are the frequent inconsistency of results, and the absence of a gradation of symptoms of damage leading to

plant death. Resistance in the seedlings of Ptb 33 and IR 26 persisted in the 30 and 60 day old plants. But the seedling resistance noted in IR 329, Jyothi and Milyang 30 was lost in the later stages of plant growth. On the other hand varieties such as Mudgo, Ptb 21 and Suduru samba, which were susceptible in seedling stage, proved resistant at later stages.

Pathak and Khush (1979) stated that the methodology used in mass rearing and screening of the test lines in IRRI was similar to that described by Choi (1979). They have stated that in retesting, selected cultivars for resistance, insects are caged on individual potted plants and records are taken of their body size and survival and of the rate of growth of nymphs or longivity of adults. In determining the insects ovipositional and feeding preferences, the insects were released into a cage containing potted plants of different varieties. They have described a method to determine differences in damage to resistant and susceptible plants. For this, individual seedlings of test varieties and a susceptible check variety were transplanted separately into the 15 cm clay pots. At a desired interval after planting, each plant was confined with 100 second instar nymphs in a 60 x 30 cm cylindrical mylar

cage. Plant damage was rated on the standard scoring system of 0-9.

Medrano et al. (1987) reported that in field screening some varieties were resistant but susceptible at early seedling stage in greenhouse. So they modified the standard seed box screening test (SSST) to identify field resistant varieties in the greenhouse.

In India, Veluswamy and Chelliah (1984) evaluated 465 rice accessions for BPH resistance in the greenhouse with the commonly used seedling bulk screening technique, Rice accessions ASD 11, IET 5741, IET 6315, T7 and V.P. Samba were identified as resistant. Their resistance to BPH was further confirmed by the alternate row test and seedling screening in pots. ASD 11, IET 5741, IET 6315, T7 and V.P. Samba were confirmed to be BPH resistant. Kalode et al. (1975) conducted mass screening tests under controlled conditions in greenhouse at the AICRIP. The mass screening in the greenhouse was used to discard susceptible lines and identify possible resistant lines. In early screenings it was observed that test lines planted at either end of the tray were more likely than others to escape insect attack. Kalode et al. (1975) modified the layout to minimise such chances of escape. The method involved the

infestation of 7-10 day old seedlings of test entries in wooden trays. Each tray accommodated 20 test rows with 15 seedlings each, 2 middle rows of resistant check and 4 susceptible border rows of TN1. The wooden trays were kept in galvanized iron trays 7.5 cm deep with water to maintain humidity. Sufficient number of first and second instar nymphs were released on test lines so that each seedling was infested with 5 to 10 nymphs. When more than 90% of the susceptible check were dead, the entries were scored. Test lines with damage scores below 3 were rated as resistant in (0-5) scale. Thomas (1977) described another method for screening at the tillering stage. For this, 20 days old seedlings of each variety were transplanted in separate pots at two seedlings per hill. Twenty-five days after transplanting, the potted plants were pruned to 8 to 10 healthy tillers in a pot and placed inside a cage. One hundred second instar nymphs were released on plants in each pot. The damage is graded when the susceptible check variety is wilted on a 0-9 scale.

Pongprasert and Weerapat (1979) reported that rice varieties have been screened for resistance to BPH in Thailand since 1972. The main purpose of screening was to facilitate the quick rejection of most of the BPH

susceptible lines. The screened materials were the Thai local varieties and breeding lines, the germplasm materials and breeding lines of IRRI. Because BPH can be easily mass reared and because the natural field population is usually low, screening is generally done in the greenhouse. The methodology used in screening was the same as that described by Choi (1979).

Choi (1979) in China stated that mass rearing of BPH was essential for mass screening of varieties. Screening was conducted at the seedling stage in greenhouse. The test varieties were seeded in rows 5 cm apart in 60 x 45 x 10 cm seed boxes. A susceptible check variety and a resistant check variety were planted at random in each seed box. The boxes were placed inside a galvanised iron tray inside a screened room. About 7 days after seeding, the seedlings were infested with a large number of second and third instar nymphs. An average of 5 insects per seedling constituted as optimum population. The final damage rating was taken when about 90% of the susceptible check plants were killed-usually about 7 to 10 days after infestation. Plant damage was rated on the standard scoring system of 0-9 scale. The varieties or lines that fell into grade 1 to 3 were further evaluated for consistency of resistance.

Choi et al. (1979) used another method to screen varieties against BPH in Korea. Test varieties were seeded in rows spaced 4 cm apart in 40 x 50 x 10 cm polyethylene seed boxes. Each cultivar was planted in a 15 cm row across the width of the seed box. A susceptible check variety and a resistant check variety were planted at random in each seed box. The seeds were usually pregerminated by soaking in water at 30°C and disinfected. Twenty test varieties were accommodated in each seed box. The seed boxes were kept in a concrete or iron tray containing 5 cm of water. The bottom of each seed box has several small holes to admit water freely. The seed boxes were usually covered by a bottomless wooden cage (30 x 40 x 30 cm) covered with fine mesh nylon cloth. Seedlings at the one leaf stage were infested by scattering a large number of second and third instar nymphs on them, an average of 5 insects per seedling. Final readings were made at 10 to 14 days after infestation when all susceptible check plants have been killed.

At the central Agricultural Experiment Station, Japan, BPH were reared and screened in an insectary at 26-27°C and with 15 hrs. of light. In mass screening, 15 germinated seeds of each variety, after 2 days of incubation

at 30°C, were planted in a half row in a tray. Usually 20 half rows including two replications of check rows were grown in trays. After 2 days in a lighted incubator, seedlings at the early second leaf stage were infested by about 5 second and third instar nymphs. Susceptible plants were killed within 5-7 days after infestation (Kanada and Kisimoto, 1979).

3. Mechanism of resistance

Pathak (1972) measured the gain in body weight and the amount of honeydew excreted by BPH to determine whether the insects caged on resistant and on susceptible plants feed equally well. They found that insects caged on susceptible host gained weight. The loss of weight on resistant plants was assessed more clearly by estimating the amount of honeydew excreted by the insects.

In the screening experiments, the insects exhibited a distinct non-preference for certain varieties. This reaction appeared to gustatory rather than olfactory or visual since the insects did not exhibit any difference in their alighting behaviour on different varieties but they did not stay on resistant plants for sustained feeding (Sogawa and Pathak, 1970). The latter response was so

strong for BPH caged on Mudgo that the insects starved to death rather than feeding on the plants. According to Sogawa and Pathak (1970), honeydew deposition by planthoppers has been used as a tool to measure the insect's food intake and the resistance of the host plant to insect attack.

Cagampang et al. (1974) reported the metabolic changes in the rice plant during infestation by BPH. He has given some of the changes in the carbohydrate and protein metabolism and in the water status of rice plants infected by BPH. In leaf blades infested by adults, the chlorophyll, moisture, soluble protein and protease activity decreased but the level of free amino acid and amino element incorporation increased in comparison with leaf blades of uninfested plants. Similar effects were detected in the leaf sheaths of infested plants and their dry weights. Levels of sugars were lower than those of the uninfested plants. Heavy infestation resulted in an increase of more than 30 fold in the levels of arginine, asparagine, lysine, proline and tryptophan and a 6-fold increase in free amino acids in leaf blades. Increasingly severe plant hopper damage to the plant was accompanied by a decline in the rate of uptake of leucine. A restriction of the feeding

site to either the leaf blades or the leaf sheath resulted in localised damage. In a study on the influence of the stage of the BPH and plant age on insect survival on resistant varieties, Medrano and Heinrichs (1980) found that survival of fifth instar nymphs was significantly lower than that of first and third instar nymphs on resistant seedlings of 60 days old and survival of all instars was low. The fifth instar nymphs showed the maximum differences in survival. Sogawa (1980) investigated four behavioural and physiological characters (Host preference, honeydew excretion, nymphal development and fecundity) of the three biotypes of BPH. The three biotypes were most clearly distinguished from each other on the basis of their average abilities to feed and reproduce on different rice varieties. Malabuyoc and Heinrichs (1981) reported, honeydew excretion, feeding activity and insect weight gain as criteria in determining levels of varietal resistance in the green leaf hopper in Philippines. Weight of honeydew excreted in the susceptible variety TN1 was 2.5 times that excreted on the resistant variety IR 29 and weight of assimilated food on TN1 was 13 times that on IR 29. This indicated that although feeding was substantial on both varieties, most of the intake on IR 29 was not assimilated. Pathak (1972) reported that no mechanical barrier to the insects feeding was apparent in

any of the resistant variety. In fact, the insects made more feeding punctures on the resistant varieties than on susceptible varieties. The variety "Mudgo" either lacked feeding stimulus or possessed feeding repellents for BPH. Studies on the biochemical basis of resistance suggested that the resistance to BPH in Mudgo could be attributed to the lower content of asparagin in the variety.

Honeydew excretion by the hoppers is related to feeding. Sogawa (1970) observed that frequency of honeydew excretion in the adult females varied from 7 to 40 droplets/hour. The insect excreted considerable amount of sugar free matter as well as matter containing sugar, which showed that the insect ingested sap from both xylem and phloem. The honeydew also contained amino compounds. Noda et al. (1973) observed that the honeydew excreted by the hopper contained 18 aminoacids. When the insects were fed on distilled water alone, only traces of aminoacids could be detected in the honeydew and thus concluded that the free aminoacids were derived from the ingested plant sap.

Insects caged on susceptible varieties gained significantly more weight than those caged on resistant varieties. They also excreted honeydew copiously on susceptible

varieties but scantly and intermittently on resistant varieties. The amount excreted generally depended on the amount of food ingested (IRRI, 1978).

Saxena (1975) found in laboratory experiments that the odour of susceptible varieties like TN1 and IR 8 strongly attracted the hopper, while the odour of resistant varieties Mudgo and IR 26 were unattractive.

Saxena and Sogawa (1977) investigating on the factors that govern the susceptibility and resistance of rice varieties to the brown planthopper, observed that although all the tested varieties were equally suitable for oviposition, significantly lower number of eggs hatched on the resistant varieties than on susceptible ones. Further, the reduced quantities of food ingested from resistant varieties and its inefficient utilization because of lower nutrition value, lead to the poor growth of larva and reduced longivity and egg production in adults.

At the IRRI (IRRI, 1971) the nymphs of N. lugens suffered high mortality and grew slowly on resistant varieties. Consequently the population build up was also low. Morphological difference in varieties were not correlated with differences in resistance.

Kulshreshtha et al. (1976) reported that varieties Ratna and Shakthi showed tolerance under Indian conditions.

Pathak et al. (1969) observed that the variety Mudgo was highly resistant to the pest. The reduced feeding on this variety was attributed to the lack of a necessary feeding stimulus or due to the presence of a strong repellant.

Bae and Pathak (1970) studied the susceptibility of 20 selected rice varieties to BPH. They observed that while there was some antibiosis effect, tolerance to hopperburn was the major factor in the difference in susceptibility.

Krishna et al. (1976) studied preference and non-preference in Ptb 33, Ptb 21, ARC 6650 and MR 1523 which possess varying degrees of resistance. These types and the susceptible TN1 were grown in wooden flats and first and second instar nymphs were released on one week old plants. The insect counts on different varieties after 24 hours showed significant difference. TN1 attracted most of the nymphs whereas Ptb 33 attracted the fewest. This differential response suggested the possible presence of some attractant in the susceptible variety and its absence in the resistant cultivar or the absence of repellents in the susceptible type and its presence in resistant

type. Similar results were reported at IRRI (Karim, 1975) and in Korea (Choi, 1979).

Kalode et al. (1975) studied antibiosis through survival of nymphs and population build up of BPH on resistant and susceptible lines. The survival rate was intermediate on LebMueNahng and ARC 6650. Survival was affected only after 10 days of caging. Mortality was high immediately before the adult stage was reached or shortly thereafter. The population build up from 100 original nymphs on Ptb 33, Ptb 21 and MR 1523 was significantly lower than that on TN1. LebMueNahng and ARC 6650 were comparatively less favourable to the insect. Other evidences of antibiosis included lower rates of nymphal development, lower production of females and feeble development of adults. Similar effects had been reported by Sogawa and Pathak (1970) in populations reared on the variety Mudgo and on different rice varieties by Karim (1975).

Karim (1975) and Kalode et al. (1975) from their honeydew experiments reported that insect feeding on resistant cultivars was restricted. Insects on TN1 and LebMueNahng excreted heavily. The data also show a possible correlation between insect survival, population build up and honeydew excretion. Lower survival rates and lower

population build up were thus associated with less feeding on resistant varieties. The differences observed in the honeydew excretion might be used as an indirect index of the degree of resistance. Kalode et al. (1975) studied the effect of different numbers of nymphs on resistant and susceptible varieties of different ages. Two rice varieties TN1 (susceptible) and MR 1523 (resistant) were caged with different numbers of nymphs and the extent of damage to MR 1523 was noted when all TN1 plants had been killed. The 10, 15 and 20 day old MR 1523 plants retained their resistance (0.5 to 1.3) even with increasing insect numbers (5 to 15, 15 to 25 and 25 to 35 insects/plant respectively), while TN1 plants were killed at all levels of insect population and at all plant ages. In another experiment, Ptb 33, Ptb 21, Umsum, MR 1523, ARC 6650 and LebMueNahng were infested at various stages. (10, 30, 45 or 60 days after planting) with about equal numbers of insects (10, 30, 45 or 60 nymphs/plant respectively). Results indicated that plant age did not influence the degree of resistance expressed.

Biochemical analysis of selected resistant varieties showed significant increase in phenolic compounds following infestation by the hopper pests. In contrast, concentration

of total sugars and total nitrogen do not significantly change in resistant varieties following pest infestation, while in susceptible check TN1, infestation by hoppers considerably depleted these compounds. The analysis of honeydew of the three hopper species indicated higher quantities of total amino acids when they were feeding on susceptible TN1 as compared to that collected during feeding on resistant varieties (DRR, 1987).

The response of Chianonshell, a newly developed rice variety resistant to BPH and several other resistant varieties to artificial and natural infestation by the pest was determined in laboratory and in field tests in Taiwan by Cheng (1976). The main resistance mechanism of Chianonshell and some other resistant selections was found to be nonpreference and to a lesser extent, tolerance of attacks rather than antibiosis.

When the resistant mechanism of rice lines bred from an original cross between a susceptible japonica cultivar and a highly resistant indica cultivar (Mudgo) were investigated by Hirao and Todoroki (1975) in Japan, in the laboratory and field tests, nonpreference appeared to be the most important factor followed by tolerance and antibiosis. Nonpreference of the adult for older plants was more apparent

than that for seedlings.

Choi (1980) in Korea found that resistant varieties were nonpreferred for feeding but not always for oviposition. On resistant varieties, N. lugens suffered severe mortality, had a slower growth rate than on susceptible varieties and laid fewer eggs from which fewer adults developed, all possibly as a result of less feeding on resistant than on susceptible varieties.

4. Biotypes of BPH

Fernando et al. (1979) reported that N. lugens from Sri Lanka showed plant reactions and insect survival and development markedly different from those from the Philippines. Most of the rice varieties found resistant to Philippines biotypes, originated in Sri Lanka, where for several hundred years they had been exposed to the N. lugens populations. The studies confirm that the BPH found in Sri Lanka differs greatly from the biotypes found in the Philippines. The varieties Ptb 33, ARC 6650, Rathal 518 and Sudurusamba showed marked resistance to the pest, and ASD 7, Mudgo, IR 36 and IR 38, which were found to be resistant to the Philippines races, were highly susceptible to the Sri Lankan biotype.

Feur (1976) reported the occurrence of attacks by BPH on the resistant rice varieties IR 26, IR 1561-2283, IR 28 and IR 30 which have the dominant gene for resistance ie. Bph1 in Southern Philippines. The variety IR 36 resistant to biotypes 1 and 2 with bph2 gene for resistance was attacked by N. lugens throughout South Philippines.

Pathak and Khush (1979) stated that several biotypes of the BPH existed. According to them the BPH biotype in India and Sri Lanka are apparently different from all the three biotypes and is more prolific. Biotype 1, the type that generally exists at IRRI, biotype 2, capable of surviving on plants of such varieties as Mudgo and IR 26 which carry Bph1 gene for resistance and Biotype 3, which survives on varieties carrying bph2 gene for resistance such as ASD7, Ptb 18 and IR 32. Varieties with Bph1 are resistant to IRRI biotype 1 and 3 and varieties with Bph2 are resistant to IRRI biotypes 1 and 2. However, varieties with Bph3 and bph4 are resistant to all the three biotypes. Such varieties are also resistant in India and Sri Lanka, whereas the varieties with Bph1 and bph2 are susceptible there.

The results from an international screening programme carried out in several test sites of Asia provided valuable

information on biotype variations. Seshu and Kauffmann (1980) reported that several breeding lines derived from Ptb 33 were promising in all test sites of Asia and Solomon islands. Genes conveying resistance to N. lugens in Ptb 33 in South Asia appear to be different from those in the rest of Asia as is evident from the differential reactions of semidwarf selections from that variety.

Sogawa (1980) carried out laboratory investigations in the Philippines on the biology and genetics of the three biotypes (1, 2 and 3) of N. lugens that are being maintained as inbred populations on the susceptible variety TN1 as well as resistant varieties Mudgo and ASD 7, IR 24 and TN1 susceptible to all the 3 biotypes, IR 26 resistant to biotypes 1 and 3 but susceptible to 2 and IR 40 resistant to biotype 1 and 2 but susceptible to 3. The biological characters of biotypes 2 and 3 were generally inherited in a recessive or intermediate manner when these biotypes were hybridized with biotype 1.

Peralta et al. (1983) reported upto 5% damage due to N. lugens on nearly mature plants of the resistant variety IR 36, indicating the evolution of resistant types of the pest in Mendanao, Philippines.

Saxena and Barrion (1983) reported that biotype 1 of N. lugens can survive on and can damage rice varieties which do not carry genes for resistance, while biotype 2 survives on resistant varieties carrying the Bph1 gene and biotype 3 survives on varieties carrying the gene bph2. However, none of these biotypes survived on varieties carrying genes Bph3 or bph4. Several varieties which are resistant in Philippines are susceptible in India and Sri Lanka as South Asian biotypes are more virulent than South East Asian biotypes.

Sogawa et al. (1984) studied the characterisation of the BPH population on IR 42 in North Sumatra. They compared the BPH population collected from IR 42 in North Sumatra with that of the known biotypes by two honey tests. The N.S. population was differentiated from biotype 2 by a poor ability to feed on IR 26 and from biotypes 1 and 3 by an improved ability to feed on IR 42. The N.S. population excreted as much honeydew on bph2 resistant varieties ASD 7 and IR 42 as on susceptible variety Pilita 1/1 but excreted strikingly less honeydew on Babawee, IR 56, Mudgo and IR 36. This indicated that N.S. population belongs to biotype 3 which has specific ability to feed on bph2 resistant varieties. The biological characteristics of the

three biotypes of N. lugens that differ in their ability to infest resistant varieties of rice were compared in the Philippines by Sogawa (1981). The three biotypes could most readily be differentiated. In addition, biotype 3 differed significantly from the others, especially biotype 1, in its feeding effect, food plant preference and nymphal development on resistant varieties. Medrano and Heinrichs (1985) reported from their studies using different biotypes of BPH in Mindanao, Philippines that in the seed box screening test, both Bph1 (Mudgo) and bph2 (IR 36 and IR 42) varieties were damaged by all the Mindanao colonies indicating that the Mindanao collections represent a biotype different from previously identified biotypes 2 and 3.

According to IRRI (1982) reactions of differential varieties to feeding of the Brown planthopper in tests conducted throughout Asia indicated that the South Asian BPH population is distinct from that of Oceania, East Asia, and South east Asia. Within India, there may be a slight difference in the Hyderabad, Coimbatore and Pantnagar populations. Four distinct BPH populations can be recognised in Asia from the reaction of differential varieties. The wild type populations in East and South east Asia and Oceania belong to biotype 1. Biotype 2 became predominant in the

Solomon Islands, Indonesia, Philippines and Vietnam after IR 26 was widely grown. Biotype 3 is being maintained in the laboratory in the Philippines. Biotype 4 occurs in India, Bangladesh, and Sri Lanka. Varieties with Bph1 gene are resistant to biotype 1 and 3, whereas varieties with bph2 gene convey resistance to biotype 1 and 2. Varieties with Bph3 and bph4 genes are resistant to all biotype with the possible exception of Pantnagar (India) populations.

Saxena and Rueda (1983) reported morphological variations among three BPH biotypes in Philippines. They maintained 100 adults from each biotype population on TN1 (biotype 1), Mudgo (biotype 2) and ASD 7 (biotype 3) and conducted morphological examinations. Multiple discriminant analysis using stepwise selection through Wilk's specification indicated distinct segregation of the three biotypes. Scatter diagrams, based on computed discriminant scores of the three biotypes, showed a high degree of segregation. Hoppers classified using leg and antennal characters exhibited a 100% probability of correct morphological identification of the three biotypes.

Veluswamy et al. (1984) recorded that known differential varieties and selected rice accessions reacted

similarly to BPH from Tamil Nadu and Pondichery, but Mudgo and ASD 7 rices carrying Bph1 and bph2 genes were susceptible to BPH populations from Tamil Nadu and Pondichery, while RatuHeenati (Bph3) and Babawee (bph4) were resistant. ARC 6650, ARC 10550, IET 5741, IET 6315, T7, ASD 11, Sinnasivappu and V.P. Samba showed consistently resistant reactions to BPH from Tamil Nadu and Pondichery. ARC 6650, RatuHeenati, Babawee and Sinnasivappu are resistant to BPH biotype 1, biotype 2 and biotype 3 in Philippines but IET 5741, IET 6315, T7, ASD 11 and V.P. Samba are highly susceptible. Thus the Bph1 and bph2 genes did not confer resistance to the BPH population of Tamil Nadu and Pondichery, however, Bph3 and bph4 genes conferred resistance to BPH populations occurring in Philippines and in S.India. ARC 6650 and Sinnasivappu also possessed a high level of resistance to the Philippines and the S.Indian BPH populations. These differential varietal reactions indicated that the BPH population in Tamil Nadu and Pondichery is different from the South East Asian populations. Thomas (1976) found that varieties Ptb 19, Ptb 33 and ARC 6650 showed resistance in seedling tests in Kerala. Most varieties reported as resistant in Philippines were found to be susceptible in S.India and Sri Lanka due to the existence of different biotypes. Varieties Ptb 33 and ARC 6650 were found to be resistant to

all the three biotypes (IRRI, 1976).

Shrestha et al. (1987) multiplied the local BPH population in Nepal. The biotype was identified by screening on differential rice varieties in greenhouse. Mudgo and IR 26 with Bph1 gene (resistant to biotypes 1 and 3) were susceptible to Parwanipur biotype. ASD 7, CR 94-13 and IR 36 with bph2 gene (R to biotypes 1 and 2 but susceptible to biotype 3) were susceptible. The Parwanipur BPH population is not biotype 1, biotype 2 or biotype 3. RatuHeenati (Bph3 gene) and Babawee (bph4 gene) were resistant to Parwanipur biotype, as were Ptb 33 and Hondarawala with two genes (bph2 + Bph3) for resistance. The Parwanipur BPH appears to be a new biotype.

Hollander et al. (1981) reported that as the resistance of rice varieties to N. lugens is based on major genes it has been widely assumed that there is a gene for gene correspondence between resistance on the part of the plant and virulence on the part of the insect. However, the mode of inheritance and response of the biotypes of N. lugens to selection, together with the previously reported wide variation within each biotype and the large overlap between them in virulence, is all consistent, with a polygenic determination of virulence.

In genetic studies on resistance to biotypes of BPH in rice, Lin and Huang (1981) tested two lines and three varieties against 5 biotypes. IR 13539-11-1 was resistant to biotype 1, 2 and 3 and 5 and IR 17488-2-2-1 was resistant to biotypes 1, 2, 3 and 4. Taichungsenyu 223 was resistant to 1 and 3, Taichungsenyu 10 was moderately resistant to 1 and resistant to 2.

Studies by Peng (1981) showed that the biotype of N. lugens present in Changsha District in China was biotype 1. Varieties exhibiting resistance to this biotype included IR 26, IR 36 and others with resistance genes Bph3 and bph4.

From the investigations on the distribution of different biotypes of BPH among those plant hoppers migrating to Korea on prevailing low pressure wind from China, Lee et al. (1983 a) collected 78 samples of females of which 61 were of biotype 1, eight were of biotype 2 and nine were of biotype 3. Lee et al. (1983 b) reported that rice cultivars Milyang 64 and Milyang 66 were resistant to biotypes 1 and 2 of N. lugens at the seedling stage in screenhouse. Milyang 65 was however, resistant to biotype 1 only.

5. Genetics of resistance

Fernando et al. (1979) in Sri Lanka studied the genetics of BPH resistance and investigated on Ptb 33 and TN1. The F_1 plants of TN1 and Ptb 33 were resistant, indicating that resistance is dominant. The F_2 and backcross data suggested that Ptb 33 has a single dominant gene for BPH resistance. Studies on the inheritance of resistance to BPH were initiated at IRRI since 1968. Athwal et al. (1971) analysed four resistant varieties and identified two loci for resistance. Dominant alleles at Bph1 locus govern resistance in varieties Mudgo, CO 22 and MTU 15 and recessive gene bph2 conveys resistance in ASD 7. Recombination between Bph1 and bph2 has not been observed. In 1972, two more varieties were investigated, MGL 2 and Ptb 18 with Bph1 and bph2 respectively.

Two breeding lines of improved plant type, IR 747-B2-6 and IR 1154-243, were resistant to BPH in the field during 1969. These lines were selected from crosses between varieties susceptible to BPH. Martinez and Khush (1974) studied the inheritance in these lines and found that IR 1154-243 has a recessive gene that is allelic to bph2 and IR 747-B2-6 has a dominant gene for resistance, that is allelic to Bph1. Martinez and Khush (1974) found

that crosses between TKM 6, one of the susceptible parents of IR 747-B2-6 and other susceptible parents such as TN1, IR 20 and IR 24, yielded a small progeny that is resistant to BPH. They concluded that TKM 6 is homozygous for Bph1 and a dominant inhibitory gene I-Bph1, the latter inhibiting the action of the former. In the crosses of TKM 6 and other susceptible varieties, individuals that inherit Bph1 but not I-Bph1 show resistant action. The genetic analysis of 28 varieties was conducted by Leksminarayana and Khush (1977) to identify two new genes. A dominant gene Bph3 in RatuHeenati segregates independently of Bph1. A recessive gene designated bph4 conveys resistance in Babawee. It segregates, independently of bph2. Nine of the varieties identified had Bph1 and 16 had bph2. One variety had two genes.

The genetic analysis of 20 new varieties has been completed by Sidhu and Khush (1978). Seven of those varieties have Bph3 and ten have bph4 for resistance. Three varieties Ptb 33, SuduHondarawala and Sinnasivappu have two genes for resistance, one gene appears dominant whereas the second gene appears recessive. Seshu and Kauffmann (1980) have stated that within group of varieties, Bph1, bph2, Bph3 and bph4 genes identified at IRRI, Philippines,

genes conveying resistance in Ptb 33 appear to be different in South Asia from those in the rest of Asia as is evident from the differential reaction of the semidwarf selections derived from that variety.

In India, studies on the genetics of BPH resistance are few. 120 crosses were made at AICRIP (1975). F_1 hybrids and F_2 materials were tested for reaction to BPH. The results indicated that Ptb 33, ARC 6650, ARC 14636B, ARC 7080 possess dominant gene for resistance, whereas Ptb 21, MR 1523, Unsum, LebMueNahng, ARC 14394 and ARC 15694 have recessive gene for resistance (AICRIP, 1975).

Natarajan and Nair (1983) have reported that the variety Ptb 33 has two genes for resistance. Veluswamy and Chelliah (1985) studied the genetic analysis of resistance to BPH in selected rices. ASD 11, IET 5741, IET 6215, T7 and VPSamba were identified as resistant in green house screening at Coimbatore. They studied the genetics of resistance of these varieties by crossing each with the susceptible variety Vaigai. The F_1 seedlings were resistant to BPH in all the crosses indicating the dominant nature of resistance. The F_2 population segregated as 3 resistant : 1 susceptible indicating that resistance is conditioned by

a single dominant gene. The F_2 population was studied only in Vaigai/C.P. Samba. It segregated as 1 resistant: 2 segregating: 1 susceptible, thus confirming the monogenic dominant nature of BPH resistance in V.P. Samba.

Siwi et al. (1979) in Indonesia reported that rice cultivar Ptb 8 from India was found to have a single recessive gene bph2 for resistance to N. lugens. Ikeda and Kaneda (1986) reported that the varieties Balamawee, Kaharamana and Pokkali had an unknown dominant gene for BPH resistance.

Allelic reaction of resistant genes Bph1, bph2, Bph3 and bph4 have been studied by Ikeda and Kaneda (1981). The results indicated that Bph1 and bph2 are closely linked and that they segregate independently of Bph3 and bph4 which are also closely linked. The resistance of Andaragahawee and Ptb 34 was found to be monogenically controlled by Bph1 and bph2 respectively while that of Ptb 21 appeared to be controlled by bph2 and Bph3. A trisomic analysis revealed that Bph3 and bph4 are located on chromosome 7.

Lin (1980) analysed F_1 and F_2 of crosses between the susceptible indica rice variety Taichungsen 3 and

resistant varieties and lines and indicated that the resistance of Taichungsenyu 223 is controlled by the dominant gene, Bph1. Resistance to Taichungsenyu-10 is controlled by the recessive gene bph2 and resistance in IR 135-39-11-1 is controlled by the dominant gene Bph3 and recessive gene bph4 confers resistance in IR 17488-2-2-1. Bph1 and bph2 are thought to be closely linked as also Bph3 and bph4. It was concluded that in a variety either Bph1 or bph2 may be combined with Bph3 or bph4. Lin (1982) in Taiwan screened varieties for resistance to N. lugens and indicated that Taichungsenshch 329 may carry the recessive gene bph4 and that Taichungsenshch-339 and 338 may carry the gene Bph3. Chang and Chen (1971) evaluated different varieties for resistance to N. lugens and observed that strains H-105, Muthumanikom and IR 60 were highly resistant while most local varieties were highly susceptible. Genetic studies revealed that resistance was determined by a single recessive gene.

Cheng and Chang (1979) in Taiwan studied F_1, F_2, back cross progenies and F_3 families of the susceptible x resistant crosses and showed that resistance to the BPH in rice varieties MTU 9, Sudurvi 306, Murunga 137, EK 1263, Sinnakayam was conditioned by a single dominant gene.

The results presented by Rao et al. (1987) indicate that Bph resistance is caused by two dominant complementary genes, Bph5 and Bph6 in Ptb 33 and by three genes Bph5, Bph6 and Bph7 in Andrewsali and Velluthacheera. Ptb 21 and MR 1523 carry two recessive complementary genes, bph8 and bph9, for resistance. It is necessary to find out the allelic relationship of genes in these resistant lines (Ptb 33, Andrewsali, Velluthacheera) with dominant genes for resistance with lines having recessive genes (Ptb 21 and MR 1523). It has also been stated that further studies are in progress to determine the allelic relationship of the above genes with Bph3 and Bph4 genes.

Veluswamy and Saxena (1989) have stated that although rice varieties with seven monogenic genes for resistance to Bph have been identified at IRRI, very little is known about their reaction to other Bph populations. They have evaluated varieties with Bph1, bph2, Bph3, bph4, bph5 and Bph6 genes and a variety with bph2 + Bph3 genes for resistance and found that Bph1 and bph2 genes do not confir resistance against the BPH population in Tamilnadu whereas varieties containing the other genes confir high level of resistance

6. Breeding for resistance

Basically four donor parents were used as sources of BPH resistance by Pathak and Khush (1979), two as sources of Bph1 and the other two as sources of bph2. Mudgo and IR 747-B2-6 were the sources of Bph1 and IR 1154-253 and CR 9-14 the sources of bph2. Crosses between Mudgo and IR 8 yielded progenies with good plant type but poor grain quality. Some of these progenies were crossed with IR 22 and IR 24 and several other very promising breeding lines were selected. These lines had good grain quality but were susceptible to Tungro and blast. They were crossed with Tungro and blast resistant lines and multiple resistant lines such as IR 2084, IR 2035, IR 2038, IR 2058 were obtained.

IR 747-B2-6 was identified as resistant to BPH and was included in the hybridization programme and several promising breeding lines and varieties have been obtained, the most important being IR 28, IR 29 and IR 34 (Pathak and Khush, 1979).

Pathak and Khush (1979) reported that CR 94-13 a resistant line conditioned by bph2 gene was used in hybridization programme at IRRI and 2 crosses IR 2070 and IR 2071

were particularly outstanding. The varieties IR 32, IR 38 and IR 46 were selected from IR 2070 and IR 36 and IR 42 from the cross IR 2071.

Khush and Beachell (1972) made a large number of crosses. Mudgo x IR 8 produced progeny that are highly resistant to BPH with the plant type of IR 8. The progeny of (Mudgo x IR 8) x (Peta 3 x TN1) x KhaoDwakMali have in addition excellent grains. IR 20 x (Mudgo x IR 8) progeny appeared to have resistance to stemborer, green leaf hopper and BPH but was highly susceptible to BLB and sheath blight.

Ten varieties with dominant genes were crossed with IR 1539-823, a dwarf selection having Bph1 for resistance. As expected, the F_1 progenies were resistant. The F_2 populations in the 7 crosses segregated in a ratio of 15 resistant : 1 susceptible, expected on the basis of independent segregation of 2 dominant genes for resistance. It is obvious that the dominant genes for resistance in these varieties segregated independently of Bph1 (IRRI, 1978).

Pathak and Khush (1979) reported that about half of the IRRI breeding materials have Bph1 gene and the other half have bph2 gene. Efforts are under way to incorporate Bph3 and bph4 also into the improved plant type, multiple resistance to pests and disease background.

Kaneda and Kisimoto (1979) stated that back crossing is being adopted to incorporate Bph1 and bph2 into Japanese varieties. Studies with F_2 plants possessing Bph1 suggested that the gene is significantly associated with a longer culm, while studies with F_2 plants possessing bph2 indicated no relationship between resistance and culm height.

Harahap (1981) used a bulked hybrid method in breeding to incorporate resistance to N. lugens and grassystunt virus as well as other pests and diseases into improved rice varieties. Several lines with resistance to N. lugens are under trial.

Namoto et al. (1986) reported that two BPH resistance genes (Bph1 and bph2) have been introduced from indica into japonica varieties by backcross breeding. Kanto PL4 inherited the Bph1 gene from Mudgo through Fs 324. It has a high level of antixenosis similar to Mudgo and shows antibiosis similar to or slightly weaker. Kanto PL 4 was registered in 1984 as Rice Norin PL3, a new germplasm of the Bph1 gene. Kanto PL5 was selected from the cross Asominori/IR 1154-243//2 Asominori. The early maturing IR 1154-243 was a donor of the resistance gene bph2. Kanto PL5 was registered in 1985 as Rice Norin PL4, the germplasm of bph2. The antibiosis of Kanto PL5 to BPH biotypes 1 and

2 is similar to or slightly weaker than that of IR 1154-243. At every stage of growth, Kanto PL5 shows an inhibitive effect on BPH survival and population increase.

Tibin et al. (1988) reported that none of the 8,200 japonica varieties or lines screened in 76-82 were resistant to BPH. Resistance genes can only be found in the tall traditional indica varieties of South Asia. They have transferred BPH resistance genes from indica into two japonica lines (80047 and 80079) in 1980. Using these lines as resistant sources, several promising japonica lines resistant to BPH have been developed in China. Three promising lines are 864, derived from Yankeng 2//791943/80047, 870664 derived from Yankeng 2//791943/80047//Nonken 57/IR 26 and 850041 derived from 791943/80047.

Gunavardhana et al. (1975) and Kudagamage (1976) made nearly 300 crosses with Ptb 33 as donor parent. The crossing programme include SuduHeenati, Sudurusamba, HeerathKunda and MR 1523 as additional sources of resistance. Preliminary data clearly indicated that the high levels of BPH resistance in Ptb 33 can successfully be transferred to the progeny.

Rao and Padhi (1986) identified promising rice cultivars with combined resistance to gall midge and

Brown planthopper at AICRIP. Breeding for multiple resistance to pests is being emphasised for yield stability. They evaluated 45 entries. Seven entries were resistant to BPH and three were resistant to both BPH and gall midge. The three entries are RP 2068-18-3-5, RP 2068-8-4-5 and IET 8371. RP 2068 came from the cross Swarnadhan/Velutha cheera, while IET 8371 came from the cross Phalguna x ARC 6650.

Dong and Taro (1985) reported from Solomon islands that BG 379-5 (BG 96-3 x Ptb 33) is believed to possess the Ptb 33 gene and was screened in the 1980 IR BPHN. It was highly resistant to BPH. It was released for commercial use on the Solomon islands in 1982 and until recently it has shown BPH resistance.

MATERIALS AND METHODS

MATERIALS AND METHODS

A. MATERIALS

I. Biological materials

The materials involved in this study consisted of the following.

i) One hundred and nine rice varieties and types collected from the International Rice Research Institute, Philippines; Directorate of Rice Research, Hyderabad; Central Rice Research Institute, Cuttack; Agricultural Research Station, Pattambi and Rice Research Station, Moncompu.

ii) The F_1, F_2 and F_3 generations of the crosses between eight resistant varieties and the susceptible variety, Taichung Native 1 (TN1).

iii) The F_1 and F_2 generations of the crosses between six resistant varieties in all possible combinations without reciprocals.

II. BPH rearing materials

i) Rearing cages

Wooden cages of size 50 x 50 x 100 cm were used

Figure 2

Brown planthopper rearing cage

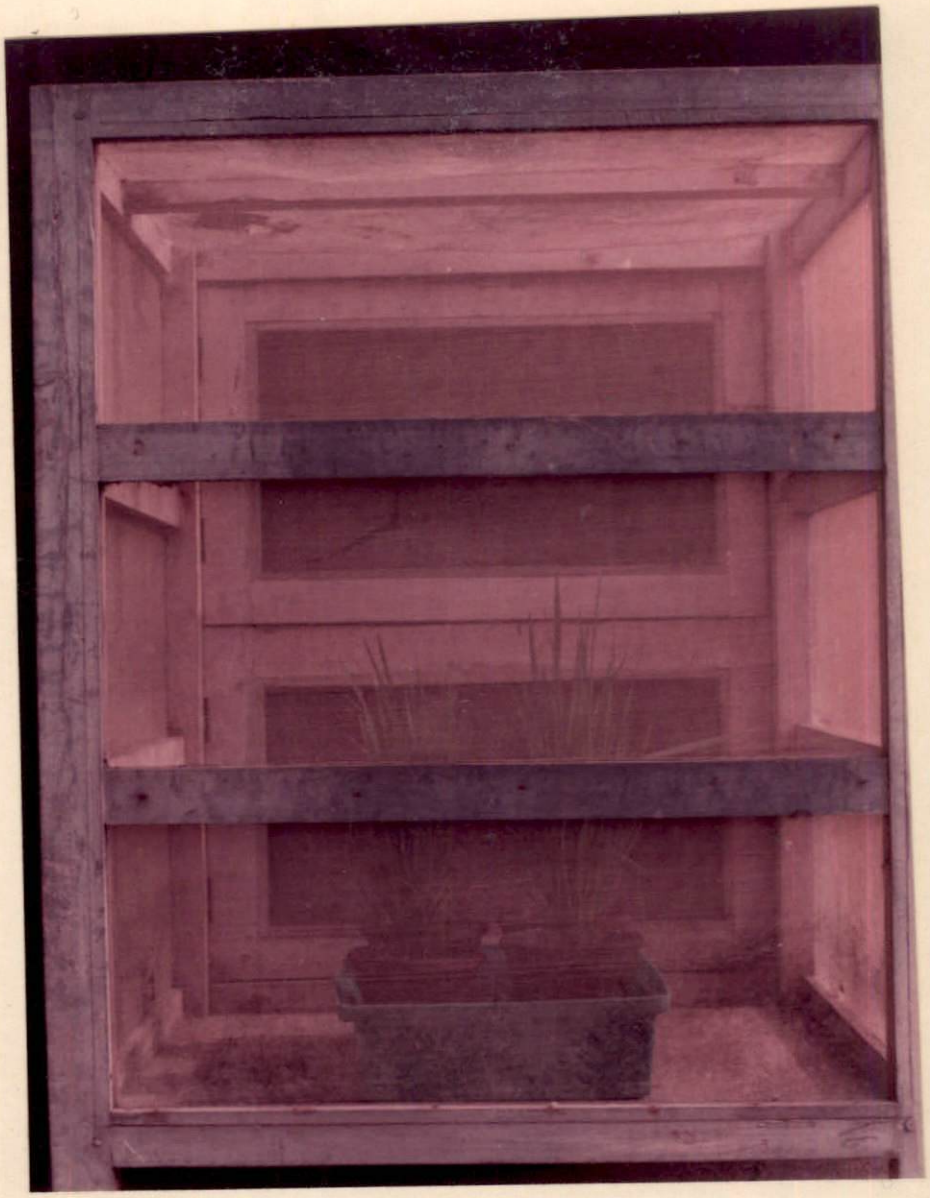


FIGURE. 2.

for rearing brown planthopper. The cage was provided with fine mesh nylon net on all sides and top. This arrangement permitted proper aeration and prevented condensation of moisture inside the cage. This also helped to prevent the entering of natural enemies of brown planthopper.

Plastic trays of size 45 x 30 x 10 cm were placed inside the rearing cages. Potted plants were kept inside these trays containing water. Four potted plants were kept in each tray. Water level in the tray was maintained by pouring water every day. The water kept in the tray helped to maintain high humidity inside the cage (Figure 2).

ii) Aspirator

A glass aspirator was used for collecting and transferring the insects.

iii) Culture of brown planthopper

Brown planthopper adults collected from the field were reared inside the laboratory. A pair of adults were isolated from this colony and they were allowed to multiply in potted plants in rearing cages. The pots were watered regularly and kept free of predators. The plants showing symptoms of wilting were replaced with fresh plants when

Figure 3

Brown planthopper screening cage

FIGURE. 3.

needed. The progenies of this pair were maintained in pure culture and they were used for screening tests.

iv) Rice plants

Forty five to fifty day old TN1 plants were used as host plants for rearing brown planthopper. Four seedlings were planted in pots of 6 cm diameter. These potted plants were kept in the plastic trays inside the rearing cages.

III. BPH Screening materials

i) Screening cages

Screening cages of size 200 x 75 x 100 cm were used for screening purpose. The cage has a wooden frame fitted with fine mesh nylon net on all sides and top to make it insect proof (Figure 3).

ii) Wooden seed boxes

The seed boxes were made of wood in which the test varieties or lines were seeded. The size of the seed box was 60 x 45 x 10 cm.

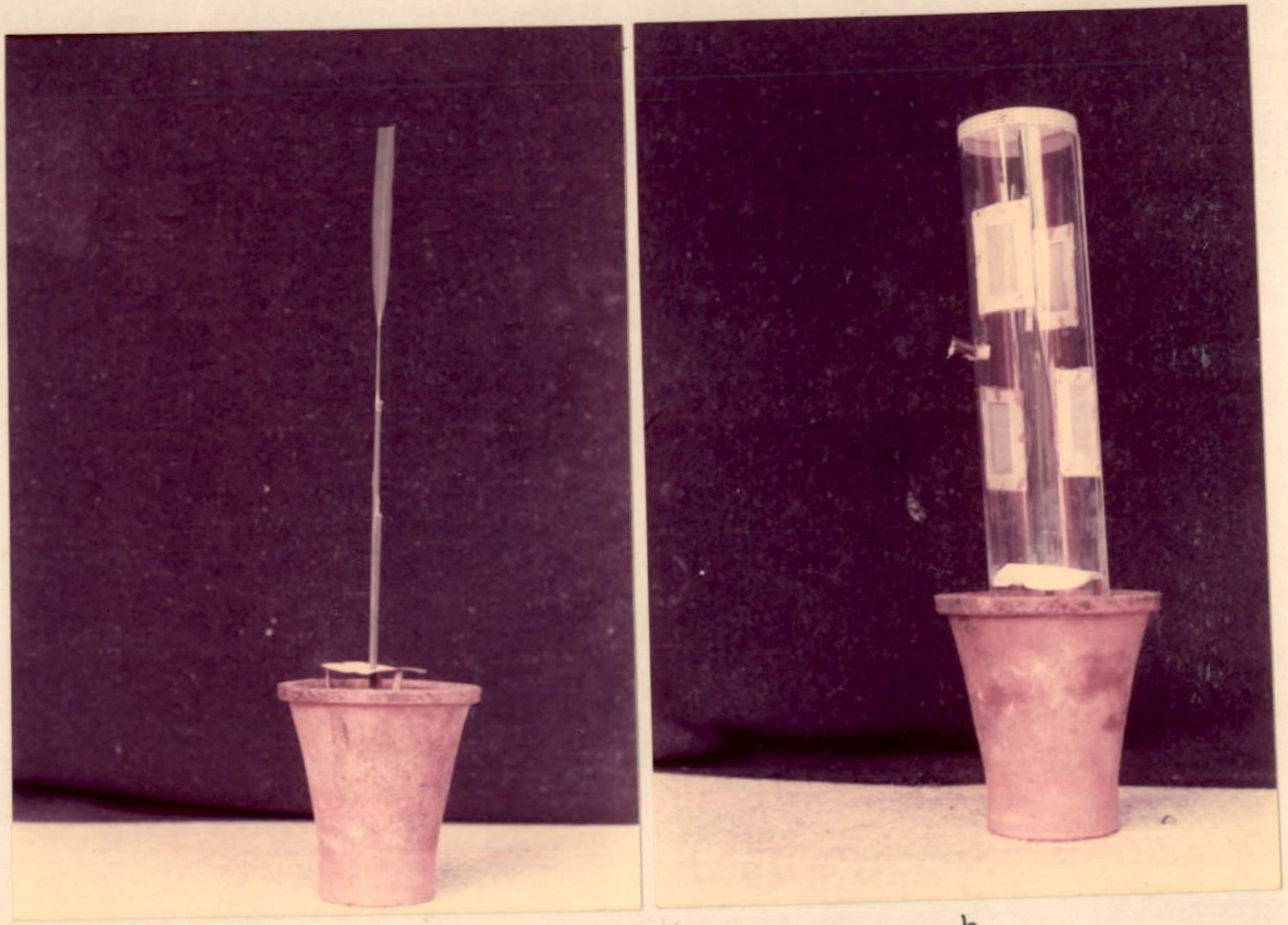
iii) Galvanized iron trays

The seed boxes were placed in galvanized iron trays

Figure 4

a) Rice plant prepared for honeydew experiment

b) Rice plant inside the feeding chamber for honeydew experiment



a.

b.

FIGURE. 4.

of size 70 x 55 x 15 cm kept inside the screening cage. About 5 cm of standing water was maintained in the tray to provide high humidity suitable for insect survival and to eliminate the need for watering the plants which may disturb the insects feeding on them. It also helped to prevent the attack of ants.

IV. Materials for Honeydew experiment

i) Feeding Chamber

A healthy potted plant in the tillering stage was taken and all the tillers except the main tiller were clipped off (Figure 4 a). A support was provided in the pot around the tiller to hold a filter paper and to prevent the filter paper coming in contact with water in the pot. The support was made by fixing three small bamboo stakes of size 6 cm length around the tiller within the pot and placing a circular card board piece on it. A slit was made in the centre of the card board piece to insert the tiller. Then a whatman No. 1 filter paper was placed on this support in the same way as the card board piece was placed. A cylindrical cage made of Polyethylene film (250/^{u}) of 40 cm length and 4.5 cm diameter was used to cover the plant. The top of the cylindrical cage was covered with nylon mesh. Ventillators covered with nylon mesh and a hole closed with

rubber cork on one side for releasing test insects on the plant were provided. The base of the cage should rest within the pot. No space was left in between the tiller and the filter paper and in between the filter paper and the cage (Figure 4 b).

ii) Glass atomiser

A glass atomiser was used to spray ninhydrin solution on the filter paper.

iii) Ninhydrin solution

Ninhydrin solution of 0.002% in acetone was used to spray on the filter paper.

iv) Transparent graph paper

A transparent graph paper was used to estimate the area of spots over the filter paper.

B. METHODS

I. Screening of varieties

i) Mass rearing of brown planthopper

The original colony was started by caging a pair of adults on TN1 plants. Colonies raised subsequently

were liberated on 50 to 60 days old potted rice plants of the variety TN1 kept in the rearing cage for egg laying. After two days, the insects were collected back from the plants. The plants were kept watered, clean and free from predators and other insects. When the plants showed symptoms of drying due to feeding by the insect colonies, which had developed on the plants, the insects were liberated on fresh plants.

ii) Collection of second instar nymphs

Fifty to sixty days old TN1 plants grown in pots were used for this. The plants were cleaned to avoid spiders and other predators before transferring to the rearing cages. Gravid females selected from the colony maintained in the insectory were released on these plants. After 24 hours, the adult insects were removed to obtain eggs of uniform age. The plants kept in rearing cages were examined daily. Second instar nymphs were seen on the leaf sheaths in 10 to 12 days.

iii) Screening

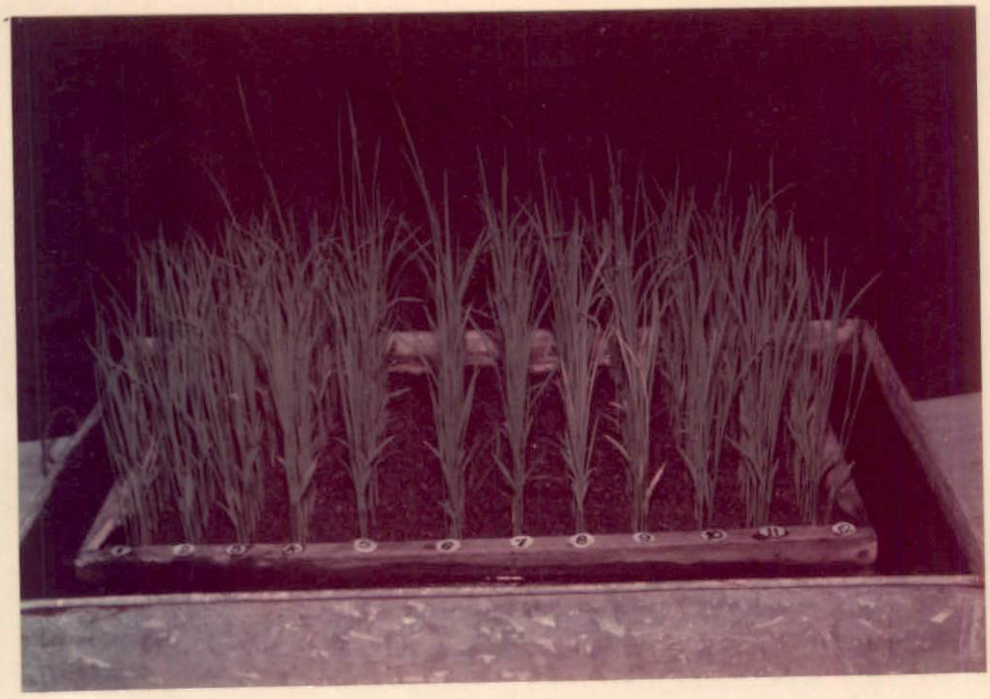
The screening of rice varieties for resistance to brown planthopper was conducted at the seedling stage by the bulk seedling test and at tillering stage by the tiller

Figure 5

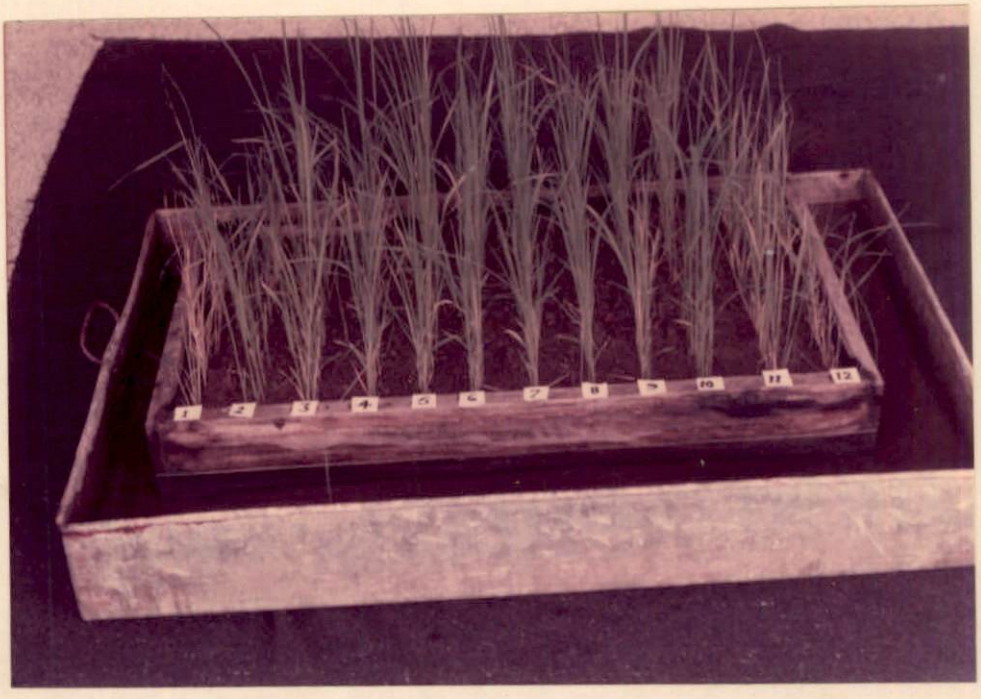
Bulk seedling test

a) Before infestation with BPH

b) One week after infestation with BPH



a.



b.

FIGURE. 5.

test and honeydew experiment.

Bulk seedling test

Seeds were sown in 60 x 45 x 10 cm wooden boxes containing garden soil to a depth of 5 cm. Each variety was sown in a row of 20 cm length along the width of the seed box. Each box contained 24 lines, 5 cm apart. Out of the 24 lines, 4 lines were of the susceptible variety TN1 and 2 lines were of the resistant variety Ptb 33. When the seedlings were of 7 days old, they were thinned to 20 seedlings per row. The seed box was placed in a galvanized iron tray of size 70 x 55 x 15 cm containing water to a depth of 5 cm and placed inside the screening cage. After seven days, the seedlings were infested by scattering a large number of second instar nymphs on them (Figure 5 a). The heavily infested plants from the rearing cages were tapped over the seedlings within the seed box as uniformly as possible so that every seedling received an average of five insects. Water was kept in the galvanized iron tray throughout the period to irrigate the seedlings, to keep high humidity and to ward off ants. The damage on the seedlings caused by the nymphs was recorded when about 90% of the plants of the susceptible check variety TN1 were killed, usually about 7 days after infestation (Figure 5 b). The

plant damage was graded on a zero to nine scale (Choi, 1979). Screening was repeated three times. The damage score and ratings were:

Damage Score	Symptom	Rating
0	No visible damage	Highly resistant (HR)
1	Partial yellowing of first leaf	Resistant (R)
3	First and second leaves partially yellow	Moderately resistant (MR)
5	Pronounced yellowing and some stunting	Moderately susceptible (MS)
7	Wilting and severe stunting	Susceptible (S)
9	All test plants dead	Highly susceptible (HS)

b) Tiller test

The varieties which were found to be resistant under seedling screening test were taken for screening at the tillering stage. Individual seedlings of the test varieties, the susceptible check variety TN1 and the resistant check variety Ptb 33 at the rate of three seedlings per pot were used in this test. There were three such pots for each variety. Twenty five days after planting the potted plants were pruned, cleaned and placed inside the screening cage in a water filled galvanized iron tray. One hundred second

instar nymphs were released on each plant. Observations on plant damage were recorded when the susceptible check variety TN1 showed 90% damage. The damage was graded on a zero to nine scale (Pathak and Khush, 1979). The damage scores and ratings are as follows:

Damage Score	Symptoms
0	No damage
3	Yellowing of 1 or 2 leaves
5	Yellowing of all leaves
7	Leaves wilted but stem is green
9	Plant dead

Damage rating

Score 0 - 3	Resistant (R)
3 - 5	Moderately resistant (MR)
5 - 7	Moderately susceptible (MS)
7 - 9	Highly susceptible (HS)

c) Honeydew experiment

The quantity of honeydew excreted was used as a criterion for the quantitative assessment of BPH feeding (IRRI, 1968). BPH excretes less honeydew when feeding on resistant plants than on susceptible ones (Choi et al., 1979). Therefore to locate the sources of resistance,

honeydew experiment was done in the varieties and types which were found resistant under seedling screening and tiller tests.

Twenty five to thirty days old potted plants were taken and all the tillers except the main tiller were clipped off. The potted plants were kept inside the feeding chamber as explained earlier. Five prestarved adult female brown planthoppers were released on the plant through the hole provided on the feeding chamber with an aspirator and the hole was closed with a cork. Care was taken to see that the filter paper was not moistered by the capillary ascent of water. This was ensured by maintaining minimum water level in the pots. After 24 hours of release, the feeding chamber was removed and the filter paper taken out with the forceps to avoid finger prints and sweat which can produce positive reaction with ninhydrin. The filter paper was sprayed with 0.002% ninhydrin solution in acetone using a fine atomiser. After spraying, the filter paper was air dried and then oven dried at 100°c for 5 minutes. Then the filter paper was taken out of the oven and the outline of the purple spots on the filter paper was marked with a pencil. The area of the spots was measured by using a transparent graph paper (Lee and Park, 1976; Pathak and

Khush, 1979; Kalode and Krishna, 1979). The plant damage was graded on a zero to nine scale. The damage score and ratings were:

Area of spot in cm^2	Damage rating
0 - 3	Resistant (R)
3 - 5	Moderately resistant (MR)
5 - 7	Moderately susceptible (MS)
7 - 9	Highly susceptible (HS)

II. Genetic analysis of resistance

i) Eight resistant varieties were selected from among the 109 varieties screened and grown in pots along with the susceptible variety TN1. The following crosses were made.

1) Eight resistant varieties with TN1 to study the mode of inheritance of resistance.

2) Six resistant varieties in all possible combinations without reciprocals to study the allelic relationship for resistance.

Wet cloth method was adopted for emasculation of the spikelets. Hand pollination of the emasculated spikelets was done with pollen collected from the desired

male parent. The pollinated panicles were protected by covering with butter paper cover immediately after dusting of the pollen.

ii) The F_1 generation of all the 23 combinations were screened for BPH resistance as follows.

1) Resistant x Susceptible crosses : 8 Numbers
2) Resistant x Resistant crosses : 15 Numbers

F_1 seedlings were screened by bulk seedling test, tiller test and honeydew experiment using thirty, nine and three seedlings respectively. The F_1 of all 23 cross combinations were selfed and F_2 seeds harvested separately.

iii) The F_2 progenies were screened by the bulk seedling test and tiller tests using a minimum of 200 and nine seedlings respectively. Nine resistant F_2 plants having a damage score of 1 and less than 1 from each cross were selfed and F_3 seeds were collected from each plants separately.

iv) The F_3 progenies of the first set of eight crosses were screened using bulk seedling test. About 100 seedlings were screened in each progeny.

Plants in each of the F_2 and F_3 progenies were scored separately as resistant and susceptible ones and the

observed segregation ratios were tested against the expected by applying the test of goodness of fit.

RESULTS

RESULTS

I. Collection of varieties and types

One hundred and nine types were collected from different sources. Detailed identity of these types are given in Table 1. Eight varieties belong to Sri Lanka, 21 to Philippines, 75 to India, three to Indonesia and two to Taiwan. Based on duration, they were grouped into long (above 120 days), medium (110-120 days) and short (below 110 days) duration types. Twentysix types belonged to the first group, 67 to the second group and 16 to the last group. The 26 long duration types were from Sri Lanka and India. The types from Philippines were of medium duration. The short duration types were from India and Taiwan.

Based on photosensitivity, the types were classified as photosensitive, nonsensitive and weakly sensitive. Twenty-seven types belonged to photosensitive group, 81 to non-sensitive and one to the weakly sensitive group. Out of the 27 photosensitive types, eight were from Sri Lanka, 18 from India and one from Indonesia. All the types from Philippines were nonphotosensitive. The only weakly photosensitive type (MO 4) was from India. The types from India were included in all the three categories. The two types from Taiwan

Table 1 Detailed identity of the Types.

Sl. No.	Designation	Source	Duration (seed to seed) (days)	Photo-sensitivity	Stature	Grain type
1	2	3	4	5	6	7
1.	RatuHeenati	Sri Lanka	135	Photo-sensitive	Tall	Long bold
2.	Babawee	"	"	"	"	"
3.	Vellai-Langayan	"	"	"	"	Med. bold
4.	Sinnasivappu	"	"	"	"	Short bold
5.	SuduHondarawala	"	"	"	"	Med. bold
6.	LekhamSamba	"	"	"	"	Short bold
7.	MuduKiriyal	"	"	"	"	Med. bold
8.	KuruHondarawala	"	"	"	"	"
9.	IR 21937-88-3-2-2-2	Philippines	120	Non sensi-tive	Dwarf	Fine
10.	IR 25588-85-3-2	"	"	"	"	"
11.	IR 9729-67-3	"	"	"	"	"
12.	IR 27325-27-3-3	"	"	"	"	"

Table 1 (contd.)

1	2	3	4	5	6	7
13.	IR 40	Philippines	120	Non sensitive	Dwarf	Fine
14.	IR 2797-125-3-2-2-2	"	"	"	"	"
15.	IR 28	"	"	"	"	"
16.	IR 9698-16-3-3-2	"	"	"	"	"
17.	IR 25924-92-1-3	"	"	"	"	"
18.	IR 52	"	"	"	"	"
19.	IR 38	"	115	"	"	"
20.	IR 54	"	120	"	"	"
21.	IR 1552	"	"	"	"	"
22.	IR 25924-51-2-3	"	"	"	"	"
23.	IR 22082-41-2	"	115	"	"	"
24.	IR 24	"	120	"	"	"
25.	IR 5741-73-2-3	"	"	"	"	"
26.	IR 9830-26-3-3	"	"	"	"	"
27.	IR 9672-140-2-3-2-2	"	"	"	"	"

Table 1 (contd.)

1	2	3	4	5	6	11
28.	IR 50	Philippines	120	Non sensitive	Dwarf	Fine
29.	IR 13427-40-2-3-3	"	115	"	"	"
30.	Mudgo	India	"	"	Semitall	Med. Bold
31.	MTU 15	"	135	Photosensitive	Tall	Long Bold
32.	CR 266-407-4	"	110	Non sensitive	Dwarf	Short Bold
33.	RP 2695-5-7-32	"	"	"	"	"
34.	RP 2068-32-2-2	"	120	"	"	"
35.	MTU 5194	"	"	"	"	Med. Bold
36.	RP 2695-5-8-31	"	"	"	"	"
37.	MTU 5295	"	"	"	"	"
38.	RP 1351-13-22-1	"	"	"	"	Fine
39.	RP 2068-17-2-2	"	"	"	"	"
40.	RP 1579-56-1907	"	"	"	Semitall	"
41.	RP 1756-39	"	"	"	"	"
42.	TNAU BPHR 8375	"	"	"	"	"

Table 1 (contd.)

1	2	3	4	5	6	7
43.	MTU 4870	India	110	Non sensitive	Dwarf	Med. Bold
44.	RP 1015-45-114-1	"	"	"	"	"
45.	TNAU BPHR 83747	"	120	"	"	"
46.	Ptb 1	"	145	Photo sensitive	Tall	"
47.	Ptb 2	"	135	"	"	"
48.	Ptb 4	"	"	"	"	Long Bold
49.	Ptb 5	"	145	"	"	"
50.	Ptb 8	"	130	"	"	Med. Bold
51.	Ptb 9	"	"	"	"	Short Bold
52.	Ptb 10	"	100	Non sensitive	Semitall	Med. Bold
53.	Ptb 12	"	125	Photo sensitive	"	Short Bold
54.	Ptb 15	"	165	"	Tall	Fine
55.	Ptb 16	"	155	"	"	"
56.	Ptb 18	"	130	"	"	Med. Bold
57.	Ptb 19	"	140	"	"	"

Table 1 (contd.)

1	2	3	4	5	6	7
58.	Ptb 20	India	125	Photo sensitive	Semitall	Long Bold
59.	Ptb 21	"	"	"	"	Med. Bold
60.	Ptb 22	"	120	"	"	Long Bold
61.	Ptb 23	"	110	"	"	Med. Bold
62.	CR 94-13	"	115	Non sensitive	Dwarf	Fine
63.	KAU 1734-2	"	120	"	"	Med. Bold
64.	RP 1015-100-25-4	"	"	"	"	"
65.	CR 487-3	"	"	"	"	Fine
66.	Triveni	"	90	"	"	Short Bold
67.	Jyothy	"	110	"	"	Med. Bold
68.	RP 1579-1864-70-30-54	"	120	"	"	Fine
69.	KAU 2084	"	"	"	Semitall	Long Bold
70.	RP 1579-1862-22-31-52	"	"	"	Dwarf	Fine
71.	Ptb 7	"	"	"	Semitall	Med. Bold
72.	KAU 170	"	110	"	Dwarf	Short Bold

Table 1 (contd.)

1	2	3	4	5	6	7
73.	KAU 169	India	120	Non sensitive	Dwarf	Med. Bold
74.	KAU 126	"	"	"	"	"
75.	KAU 204	"	"	"	Semitall	"
76.	KAU 153-1	"	"	"	"	"
77.	KAU 168	"	"	"	Dwarf	"
78.	KAU 93	"	110	"	"	"
79.	Mo 4	"	125	Weakly sensitive	"	Short Bold
80.	Mo 5	"	120	Non sensitive	"	Long Bold
81.	Mo 6	"	"	"	"	Short Bold
82.	Mo 7	"	110	"	"	Med. Bold
83.	RP 2068-12-1-2	"	120	"	"	Fine
84.	CR 451-17	"	"	"	"	"
85.	T7	"	"	"	"	"
86	M 102	"	110	"	"	Short Bold
87.	M 6	"	120	"	"	"

Table 1 (contd.)

1	2	3	4	5	6	7
88.	M 210	India	95	Non sensitive	Dwarf	Short Bold
89.	M 2	"	115	"	"	"
90.	RP 1579-77-1579	"	120	"	"	Med. Bold
91.	RP 1015-15-7-72	"	"	"	"	Fine
92.	RP 1579-73-1864	"	"	"	"	"
93.	RP 1579-1573-15-22-30	"	"	"	"	Med. Bold
94.	RP 1579-1863-73-32-53	"	"	"	"	"
95.	CR 157-22-1900	"	"	"	"	Fine
96.	Ptb 28	"	"	"	Semitall	Med. Bold
97.	ARC 6650	"	135	Photo sensitive	Tall	Lond Bold
98.	ASD 7	"	110	Non sensitive	Dwarf	Med. Bold
99.	IET 6661	"	120	"	"	"
100.	IET 6755	"	"	"	"	Short Bold
101.	IET 6757	"	"	"	"	"
102.	IET 6759	"	"	"	"	Med. Bold

Table 1 (contd.)

1	2	3	4	5	6	7
103.	IET 7174	India	120	Non sensitive	Dwarf	Med. Bold
104.	Ptb 33 (Resistant check)	"	130	Photo sensitive	Tall	"
105.	Utri Rajappan	Indonesia	"	"	"	"
106.	M 61 B-16-4	"	120	Non sensitive	Dwarf	Fine
107.	M 66 B-45-1	"	115	"	"	Short Bold
108.	TaichungSenYu 285	Taiwan	110	"	"	"
109.	TN 1 (Susceptible check)	"	100	"	"	"

came under the nonphotosensitive group.

According to the stature of the plant, the types were grouped into tall, semitall and dwarf. Twentytwo types were tall, 72 were dwarf and 15 were semitall in stature. All the types from Sri Lanka were tall and those from the Philippines and Taiwan were dwarf. The types from India included tall, semitall and dwarf ones.

With reference to the grain type, the types were classified into four groups viz. long bold grains, medium bold grains, short bold grains and fine grains. Ten types were with long bold grains, 40 with medium bold grains, 20 with short bold grains and 39 with fine grains. The types from Sri Lanka were either medium bold grained or short bold grained. All the types from Philippines were with fine grains. All the four types of grains were seen in the Indian types. Both the types from Taiwan were with short bold grains.

II. Identification of sources of resistance

In search of sources of resistance for use in resistance breeding programmes, screening of the 109 types for brown planthopper resistance was done employing the following three methods.

i) Laboratory screening using bulk seedling test

All the types were screened using the bulk seedling test. The brown planthopper damage score and rating are recorded in Table 2. Figure 6 graphically represents the damage score of the 109 types. Among the types screened, 41 were resistant with a score of one to three (in the 0-9 scale). Twentytwo types have shown moderate resistance with a score of 3 to 5 and 13 were moderately susceptible with a score of 5 to 7. Thirtythree types were highly susceptible with a score of 7 to 9. Ptb 33 was used as the resistant check and TN1 as the susceptible check.

Of the 41 resistant types, 18 have shown a score of 2 and below. Of these, one (KuruHondarawala) comes from Sri Lanka, one (IR 1552) from Philippines, 15 (CR 266-407-4, RP 2695-5-7-32, RP 2068-32-2-2, MTU 5194, RP 2695-5-8-31, MTU 5295, MTU 4870, RP 1015-45-114-1, KAU 2084, KAU 153-1, RP 2068-17-2-2, RP 1579-56-1907, RP 1756-39, MO 6 and MO 7) from India and one (M 66-B-45-1) from Indonesia.

ii) Tiller Test of resistant types

Fortyone resistant types obtained after bulk seedling test were subjected to tiller test for further screening for BPH resistance in comparison to TN1. BPH damage

Table 2 BPH damage score and rating of types screened by Bulk screening Test.

Sl. No.	Designation	Damage score (0-9 scale)	Damage rating
1	2	3	4
1.	RatuHeenati	4.5	MR
2.	Babawee	4.6	MR
3.	Vellai-Langayan	3.2	MR
4.	Sinnasivappu	2.9	R
5.	SuduHondarawala	3.4	MR
6.	LekhamSamba	2.6	R
7.	MuduKiriyal	6.9	MS
8.	KuruHondarawala	1.2	R
9.	IR 21937-88-3-2-2-2	7.3	HS
10.	IR 25588-85-3-2	7.7	HS
11.	IR 9729-67-3	6.9	MS
12.	IR 27325-27-3-3	6.8	MS
13.	IR 40	2.4	R
14.	IR 2797-125-3-2-2	3.5	MR
15.	IR 28	4.1	MR
16.	IR 9698-16-3-3-2	4.1	MR
17.	IR 25984-92-1-3	2.5	R
18.	IR 52	6.6	MS
19.	IR 38	7.3	HS
20.	IR 54	7.3	HS

Table 2 (contd.)

1	2	3	4
21.	IR 1552	1.2	R
22.	IR 5741-73-2-3	2.8	R
23.	IR 25924-51-2-3	7.3	HS
24.	IR 22082-41-2	2.1	R
25.	IR 24	2.5	R
26.	IR 9830-26-3-3	2.7	R
27.	IR 9672-140-2-3-2-2	3.3	MR
28.	IR 50	7.9	HS
29.	IR 13427-40-2-3-3	4.0	MR
30.	Mudgo	4.1	MR
31.	MTU 15	3.2	MR
32.	CR 266-407-4	1.2	R
33.	RP 2695-5-7-32	1.5	R
34.	RP 2068-32-2-2	1.6	R
35.	MTU 5194	1.7	R
36.	RP 2695-5-8-31	1.9	R
37.	MTU 5295	1.7	R
38.	RP 1351-13-22-1	3.1	MR
39.	RP 2068-17-2-2	1.6	R
40.	RP 1579-56-1907	1.6	R
41.	RP 1756-39	1.4	R
42.	TNAU BPHR 8275	2.4	R
43.	MTU 4870	1.6	R

Table 2 (contd.)

1	2	3	4
44.	RP 1015-45-114-1	1.8	R
45.	TNAU BPHR 83747	9.0	HS
46.	Ptb 1	8.2	HS
47.	Ptb 2	7.9	HS
48.	Ptb 4	5.9	MS
49.	Ptb 5	7.2	HS
50.	Ptb 8	7.1	HS
51.	Ptb 9	7.5	HS
52.	Ptb 10	7.2	HS
53.	Ptb 12	4.5	MR
54.	Ptb 15	9.0	HS
55.	Ptb 16	9.0	HS
56.	Ptb 18	6.5	MS
57.	Ptb 19	5.2	MS
58.	Ptb 20	8.5	HS
59.	Ptb 21	4.4	MR
60.	Ptb 22	8.1	HS
61.	Ptb 23	7.9	HS
62.	CR 94-13	7.7	HS
63.	KAU 1734-2	2.9	R
64.	RP 1015-100-25-4	2.7	R
65.	CR 489-3	6.8	MS

Table 2 (contd.)

1	2	3	4
66.	Triveni	7.3	HS
67.	Jyothy	3.7	MR
68.	RP 1579-1864-70-30-54	9.0	HS
69.	KAU 2084	1.2	R
70.	RP 1579-1863-22-31-52	8.2	HS
71.	Ptb 7	8.7	HS
72.	KAU 170	3.6	MR
73.	KAU 169	2.7	R
74.	KAU 126	2.6	R
75.	KAU 204	6.5	MS
76.	KAU 153-1	1.6	R
77.	KAU 168	2.7	R
78.	KAU 93	2.2	R
79.	Mo 4	2.8	R
80.	Mo 5	2.6	R
81.	Mo 6	2.0	R
82.	Mo 7	2.0	R
83.	RP 2068-12-1-2	3.4	MR
84.	CR 451-17	3.5	MR
85.	T_7	4.2	MR
86.	M 102	2.9	R
87.	M 6	6.5	MS
88.	M 210	7.6	HS

Table 2 (contd.)

1	2	3	4
89.	M 2	4.6	MR
90.	RP 1579-77-1579	3.5	MR
91.	RP 1015-15-7-7-2	2.9	R
92.	RP 1579-73-1864	2.8	R
93.	RP 1579-1573-15-22-30	5.1	MS
94.	RP 1579-1863-73-32-53	2.8	R
95.	CR 157-22-1900	7.7	HS
96.	Ptb 28	3.4	MR
97.	ARC 6650	2.9	R
98.	ASD 7	7.2	HS
99.	IET 6661	7.5	HS
100.	IET 6755	8.0	HS
101.	IET 6757	8.5	HS
102.	IET 6759	7.8	HS
103.	IET 7174	8.5	HS
104.	Ptb 33 (Resistant check)	2.4	R
105.	Utri Rajappan	6.7	MS
106.	M 61 B-16-4	6.7	MS
107.	M 66 B-45-1	1.8	R
108.	TaichungSenYu 285	8.0	HS
109.	TN 1 (Susceptible check)	8.7	HS

R - Resistant MS - Moderately Susceptible
MR - Moderately Resistant HS - Highly Susceptible

Figure 6

Damage score in Bulk Seedling test

1. RatuHeenati
2. Babawee
3. VellaiLangayan
4. Sinnasivappu
5. SuduHondarawala
6. Lekhamsamba
7. Mudukiriyal
8. KuruHondarawala
9. IR 21937-88-3-2-2-2
10. IR 25588-85-3-2
11. IR 9729-67-3
12. IR 27325-27-3-3
13. IR 40
14. IR 2797-125-3-2-2
15. IR 28
16. IR 9698-16-3-3-2
17. IR 25984-92-1-3
18. IR 52
19. IR 38
20. IR 54
21. IR 1552
22. IR 5741-73-2-3
23. IR 25924-51-2-3
24. IR 22082-41-2
25. IR 24
26. IR 9830-26-3-3
27. IR 9672-140-2-3-2-2
28. IR 50
29. IR 13427-40-2-3-3
30. Mudgo
31. MTU 15
32. CR 266-407-4
33. RP 2695-5-7-32
34. RP 2068-32-2-2
35. MTU 5194
36. RP 2695-5-8-31
37. MTU 5295
38. RP 1351-13-22-1
39. RP 2068-17-2-2
40. RP 1579-56-1907
41. RP 1756-39
42. TNAU BPHR 8275

43. MTU 4870
44. RP 1015-45-114-1
45. TNAU BPHR 83747
46. Ptb 1
47. Ptb 2
48. Ptb 4
49. Ptb 5
50. Ptb 8
51. Ptb 9
52. Ptb 10
53. Ptb 12
54. Ptb 15
55. Ptb 16
56. Ptb 18
57. Ptb 19
58. Ptb 20
59. Ptb 21
60. Ptb 22
61. Ptb 23
62. CR 94-13
63. KAU 1734-2
64. RP 1015-100-25-4
65. CR 489-3
66. Triveni
67. Jyothy
68. RP 1579-1864-70-30-54
69. KAU 2084
70. RP 1579-1863-22-31-52
71. Ptb 7
72. KAU 170
73. KAU 169
74. KAU 126
75. KAU 204
76. KAU 153-1
77. KAU 168
78. KAU 93
79. MO 4
80. MO 5
81. MO 6
82. MO 7
83. RP 2068-12-1-2
84. CR 451-17
85. T7
86. M 102
87. M 6
88. M 210
89. M 2
90. RP 1579-77-1579
91. RP 1015-15-7-7-2
92. RP 1579-73-1864
93. RP 1579-1573-15-22-30

94. RP 1579-1863-73-32-53

95. CR 157-22-1900

96. Ptb 28

97. ARC 6650

98. ASD 7

99. IET 6661

100. IET 6755

101. IET 6757

102. IET 6759

103. IET 7174

104. Ptb 33 (Resistant check)

105. UtriRajappan

106. M 61 B-16-4

107. M 66 B-45-1

108. TaichungSenYu 285

109. TN1 (Susceptible check)

DAMAGE SCORE (0-9)
0
3
6
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109

FIGURE. 6.

score and rating are given in Table 3. Figure 7 represents graphically the damage scores of these 41 types and the check TN1.

Of the 41 types tested, 31 were resistant with a score of 0-3. Nine entries have shown moderate resistance with a score of 3-5 and one type (RP 1756-39) showed moderate susceptibility (6.3). Out of the 18 types which have shown a score of 2 and below in the bulk seedling test, 13 have shown a score of 2 and below in tiller test also. These types are KuruHondarawala from Sri Lanka, IR 1552 from Philippines, CR 266-407-4, RP 2068-32-2-2, MTU 5194, RP 2695-5-8-31, MTU 5295, RP 2068-17-2-2, RP 1579-56-1907, RP 1015-45-144-1, MO 6 and MO 7 from India and M 66 B-45-1 from Indonesia.

iii) Quantitative assay of honeydew excreted by BPH

Thirtyone types found to be resistant after bulk seedling test and tiller test were subjected to the honeydew experiment. An estimate of honeydew excreted by BPH on these types was made and the relative amount of honeydew excreted after sucking of resistant varieties is given in Table 4. Figure 8 graphically represents the relative amount of honeydew excreted by BPH on these 31 types and the check TN1.

Table 3 BPH damage score and rating of selected types screened by tiller test.

Sl. No.	Designation	Damage score (0-9)	Damage rating
1	2	3	4
1.	Sinnasivappu	3.6	MR
2.	Lekhamsamba	3.5	MR
3.	KuruHondarawala	1.6	R
4.	IR 40	2.0	R
5.	IR 25924-92-1-3	2.6	R
6.	RP 1552	1.3	R
7.	IR 5741-73-2-3	1.3	R
8.	IR 22082-41-2	2.3	R
9.	IR 24	3.6	MR
10.	IR 9830-26-3-3	3.6	MR
11.	CR 266-407-4	1.6	R
12.	RP 2695-57-32	3.6	MR
13.	RP 2068-32-2-2	1.6	R
14.	MTU 5194	1.6	R
15.	RP 2695-5-8-31	2.0	R
16.	MTU 5295	1.6	R
17.	RP 2068-17-2-2	1.6	R
18.	RP 1579-56-1907	1.0	R
19.	RP 1756-39	6.3	MS
20.	TNAU BPHR 8375	2.3	R

Table 3 (contd.)

1	2	3	4
21.	MTU 4870	2.3	R
22.	RP 1015-45-114-1	1.3	R
23.	KAU 1734-2	3.2	MR
24.	RP 1015-100-25-4	2.5	R
25.	KAU 2084	3.6	MR
26.	KAU 169	3.6	MR
27.	KAU 126	2.3	R
28.	KAU 153-1	2.3	R
29.	KAU 168	1.6	R
30.	KAU 93	3.0	R
31.	Mo 4	1.6	R
32.	Mo 5	2.0	R
33.	Mo 6	2.0	R
34.	Mo 7	1.6	R
35.	M 102	3.6	MR
36.	RP 1015-15-7-7-2	2.5	R
37.	RP 1579-73-1864	2.6	R
38.	RP 1579-1863-73-32-53	3.0	R
39.	ARC 6650	2.7	R
40.	Ptb 33 (Resistant check)	1.6	R
41.	M 66 B-45-1	1.2	R
42.	TN1 (Susceptible check)	9.0	HS

R - Resistant MR - Moderately resistant
MS - Moderately susceptible HS - Highly susceptible

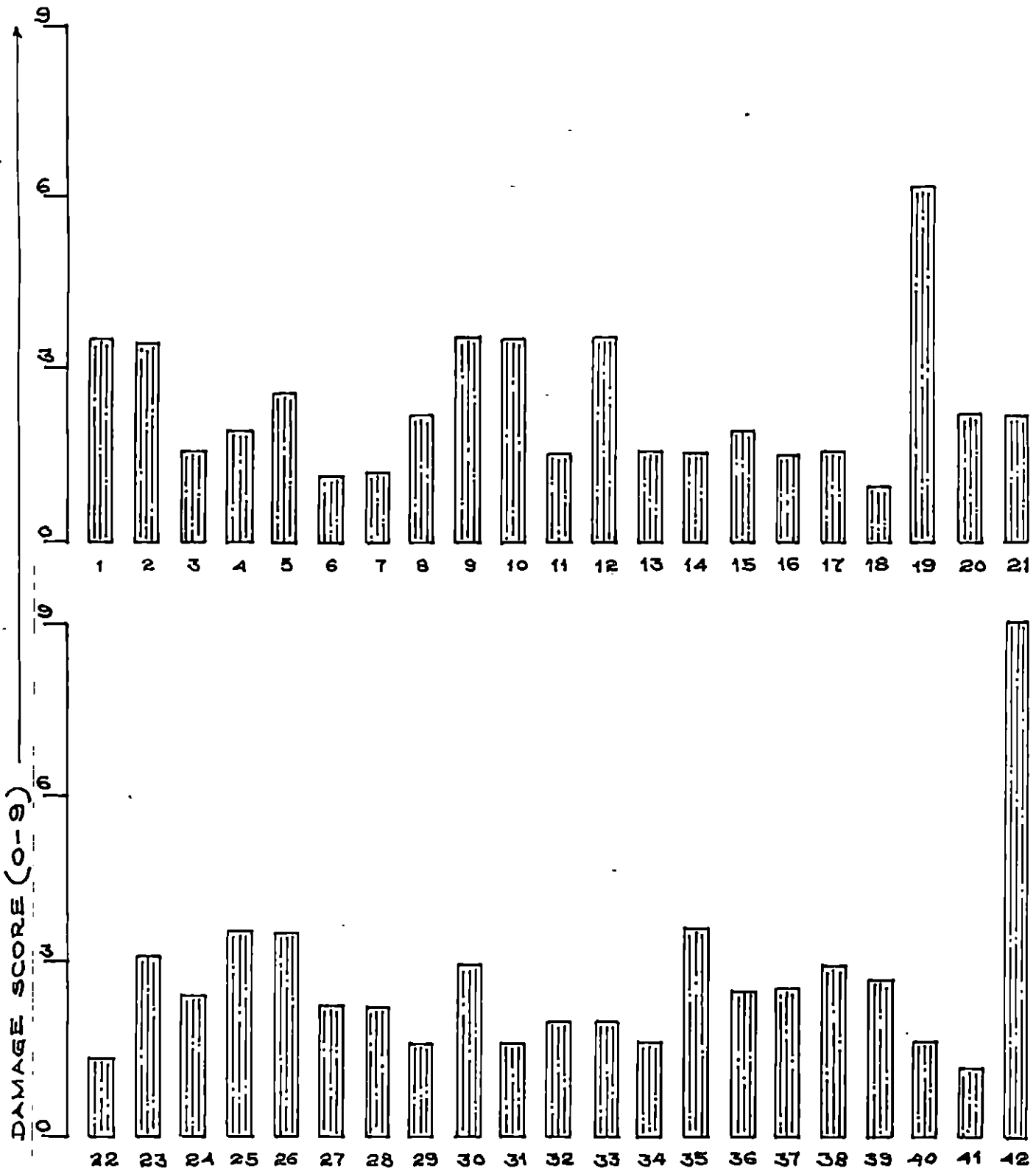

DAMAGE SCORE (0-9)
0
3
6
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

FIGURE. 7.

Figure 7

Damage score in Tiller test

1. Sinnasivappu
2. Lekhamsamba
3. KuruHondarawala
4. IR 40
5. IR 25924-92-1-3
6. RP 1552
7. IR 5741-73-2-3
8. IR 22082-41-2
9. IR 24
10. IR 9830-26-3-3
11. CR 266-407-4
12. RP 2695-57-32
13. RP 2068-32-2-2
14. MTU 5194
15. RP 2695-5-8-31
16. MTU 5295
17. RP 2068-17-2-2
18. RP 1579-56-1907
19. RP 1576-39
20. TNAU BPHR 8375
21. MTU 4870
22. RP 1015-45-114-1
23. KAU 1734-2
24. RP 1015-100-25-4
25. KAU 2084
26. KAU 169
27. KAU 126
28. KAU 153-1
29. KAU 168
30. KAU 93
31. MO 4
32. MO 5
33. MO 6
34. MO 7
35. M 102
36. RP 1015-15-7-7-2
37. RP 1579-73-1864
38. RP 1579-1863-73-32-53
39. ARC 6650
40. Ptb 33 (Resistant check)
41. M 66 B-45-1
42. TN1 (Susceptible check)

Table 4 Quantitative assay of honeydew excreted by BPH.

Sl. No.	Designation	Amount of Honeydew (cm^2)	BPH damage rating
1	2	3	4
1.	KuruHondarawala	1.90	R
2.	IR 40	1.02	R
3.	IR 25924-92-1-3	0.90	R
4.	IR 1552	0.70	R
5.	IR 5741-73-2-3	0.64	R
6.	IR 22082-41-2	1.50	R
7.	CR 266-407-4	0.70	R
8.	RP 2068-32-2-2	0.65	R
9.	MTU 5194	0.64	R
10.	RP 2695-5-8-31	1.36	R
11.	MTU 5295	0.75	R
12.	RP 2068-17-2-2	1.00	R
13.	RP 1579-56-1907	1.00	R
14.	TNAU BPHR 8375	2.10	R
15.	MTU 4870	1.36	R
16.	RP 1015-45-114-1	0.90	R
17.	RP 1015-100-25-4	1.05	R
18.	KAU 126	1.02	R
19.	KAU 153-1	1.00	R
20.	KAU 168	0.95	R

Table 4 (contd.)

1	2	3	4
21.	KAU 93	0.75	R
22.	Mo 4	0.95	R
23.	Mo 5	1.00	R
24.	Mo 6	0.75	R
25.	Mo 7	0.75	R
26.	RP 1015-15-7-7-2	1.01	R
27.	RP 1579-73-1864	3.05	MR
28.	RP 1579-1863-73-32-53	2.75	R
29.	ARC 6650	0.65	R
30.	Ptb 33 (Resistant check)	1.00	R
31.	M 66 B-45-1	1.00	R
32.	TN1 (Susceptible check)	7.50	HS

R - Resistant

MR - Moderately resistant

HS - Highly susceptible

Figure 8

Damage score in Honeydew experiment

1. KuruHondarawala
2. IR 40
3. IR 25924-92-1-3
4. IR 1552
5. IR 5741-73-2-3
6. IR 22082-41-2
7. CR 266-407-4
8. RP 2068-32-2-2
9. MTU 5194
10. RP 2695-5-8-31
11. MTU 5295
12. RP 2068-17-2-2
13. RP 1759-56-1907
14. TNAU BPHR 8375
15. MTU 4870
16. RP 1015-45-114-1
17. RP 1015-100-25-4
18. KAU 126
19. KAU 153-1
20. KAU 168
21. KAU 93
22. MO 4
23. MO 5
24. MO 6
25. MO 7
26. RP 1015-15-7-7-2
27. RP 1579-73-1864
28. RP 1579-1863-73-32-53
29. ARC 6650
30. Ptb 33 (Resistant check)
31. M 66 B-45-1
32. TN1 (Susceptible check)

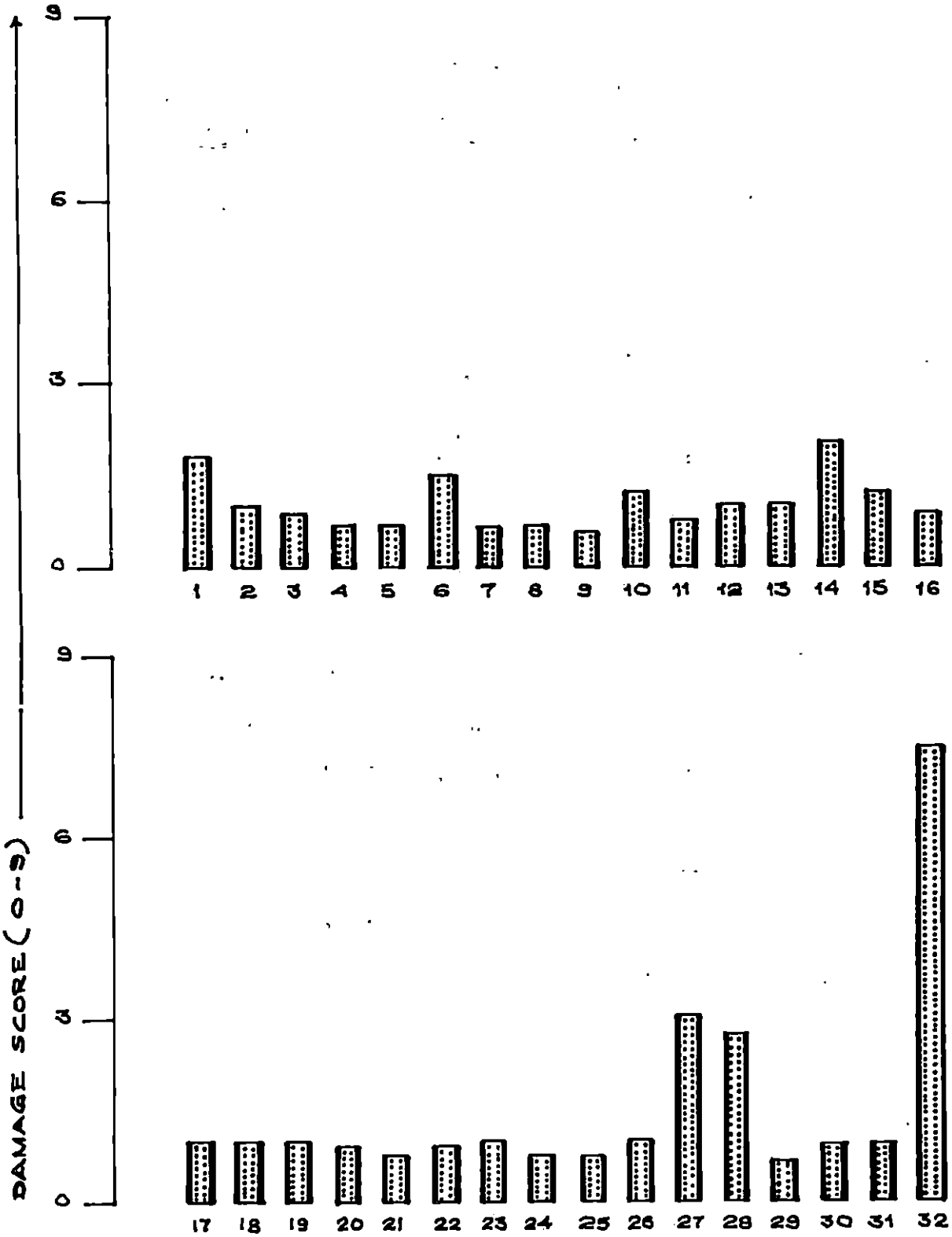

DAMAGE SCORE (0-9)
9
6
3
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

FIGURE.8.

Results of honeydew experiment revealed that the relative amount of honeydew excreted by female adults of BPH was much less after feeding on all the 31 resistant varieties than after feeding on the susceptible check variety TN1. Damage rating was done based on the amount of honeydew excreted which is represented in Figure 9. Of the 31 resistant types tested, 30 have shown resistance and one has shown moderate resistance (score 3.05) as compared to the susceptible check variety TN1.

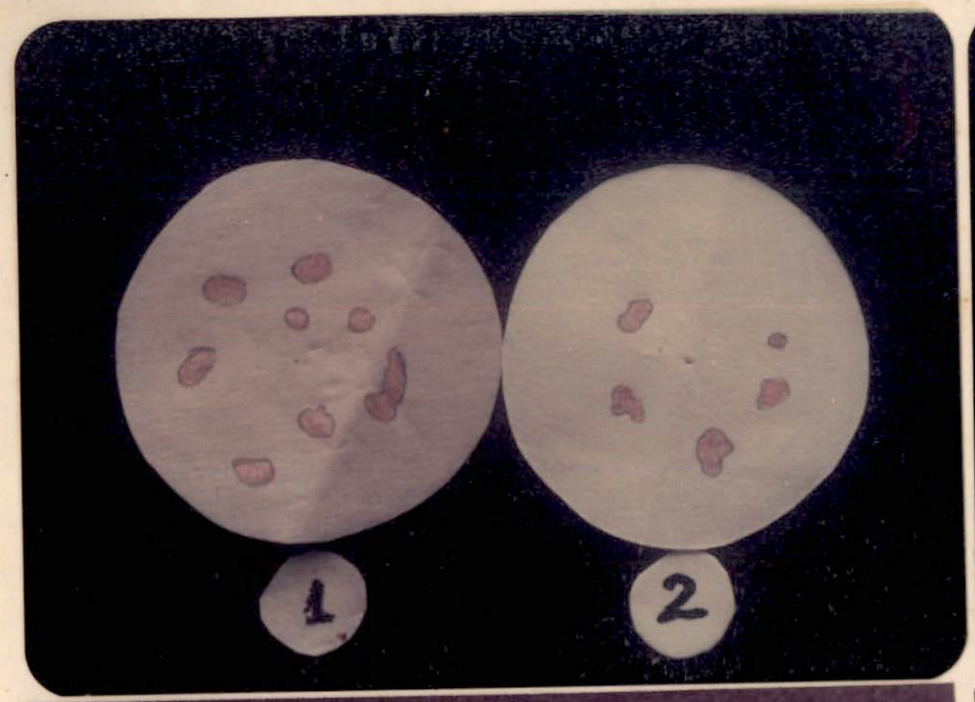
The BPH score and damage rating in bulk seedling test, tiller test and honeydew experiment of 30 resistant types along with TN1 are given in Table 5 and graphically presented in Figure 10. These 30 resistant types and TN1 are shown in Figure 11. They differ in respect of morphological characters and duration.

The thirteen types which have shown a high score for BPH resistance consistently in bulk seedling test and tiller test have shown a score of below 2 in honeydew experiment also. Of these, one was from Sri Lanka with tall stature, long duration, photosensitivity and medium bold grains (KuruHondarawala). Another type (IR 1552) was from Philippines with medium duration, nonphotosensitivity, dwarf stature and fine grains. Three types (RP 2068-32-2-2,

Figure 9

Honeydew deposited on filter paper

1. KuruHondarawala
2. IR 40
3. IR 25924-92-1-3
4. IR 1552
5. IR 5741-73-2-3
6. IR 22082-41-2
7. CR 266-407-4
8. RP 2068-32-2-2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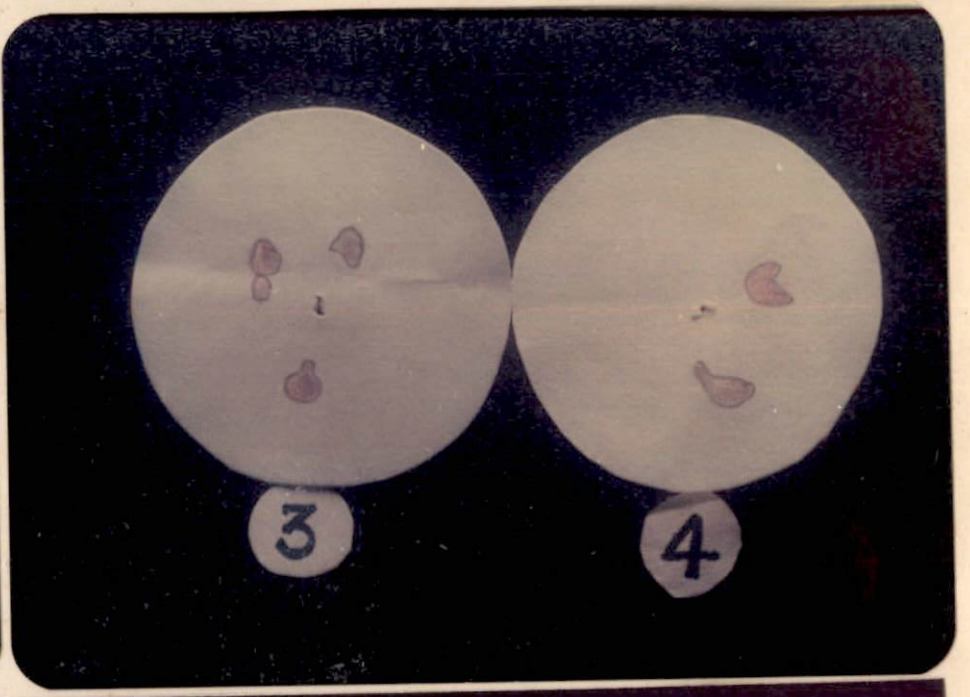
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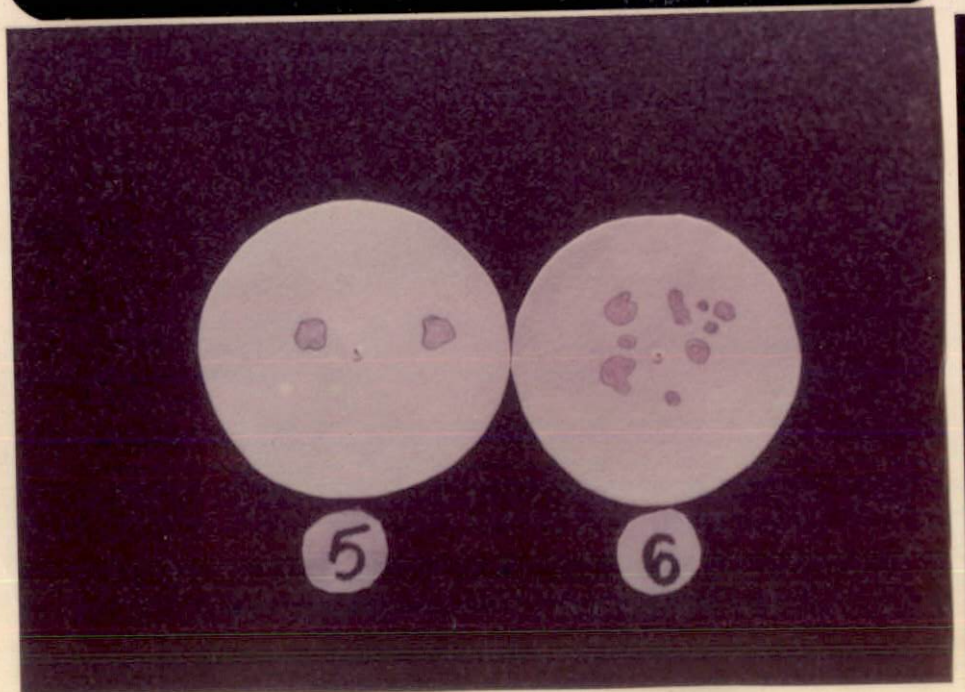

5
6

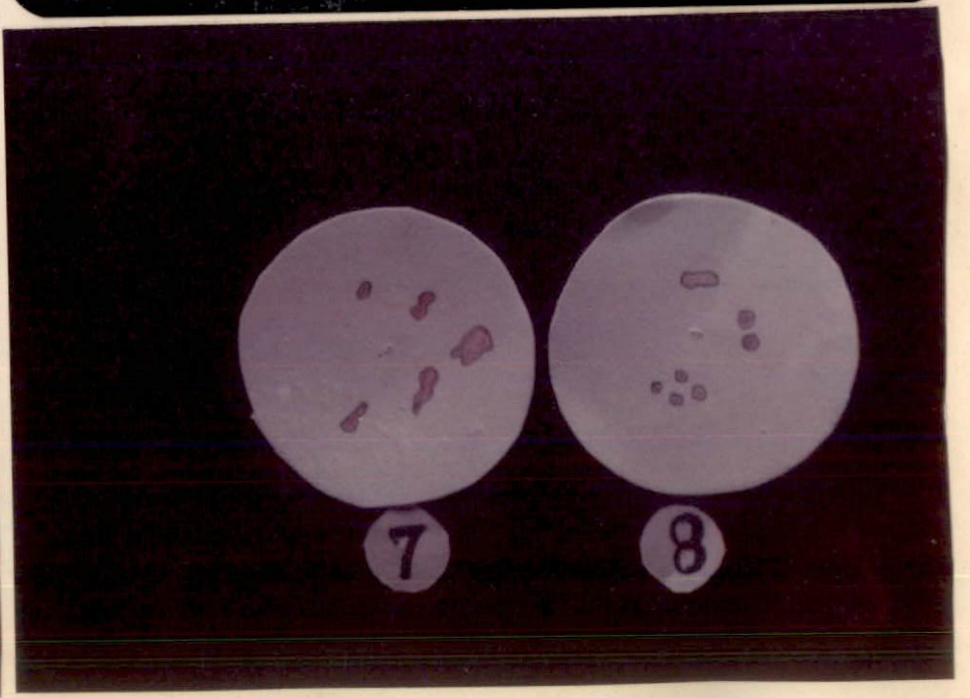
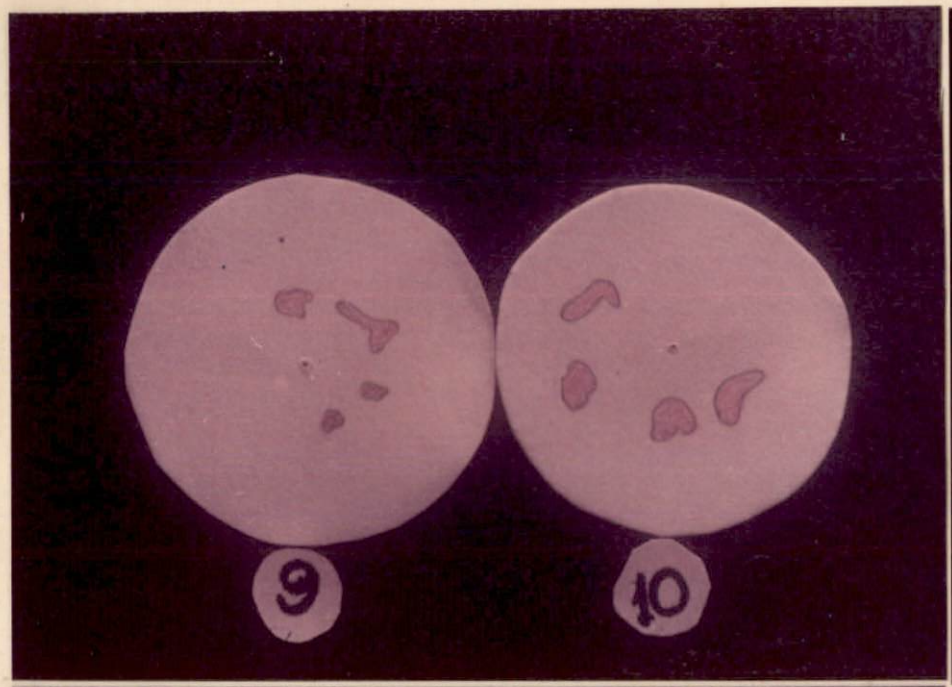

7
8

Figure 9 (contd.)

9. MTU 5194
10. RP 2695-5-8-31
11. MTU 5295
12. RP 2068-17-2-2
13. RP 1579-56-1907
14. TNAU BPHR 8375
15. MTU 4870
16. RP 1015-45-114-1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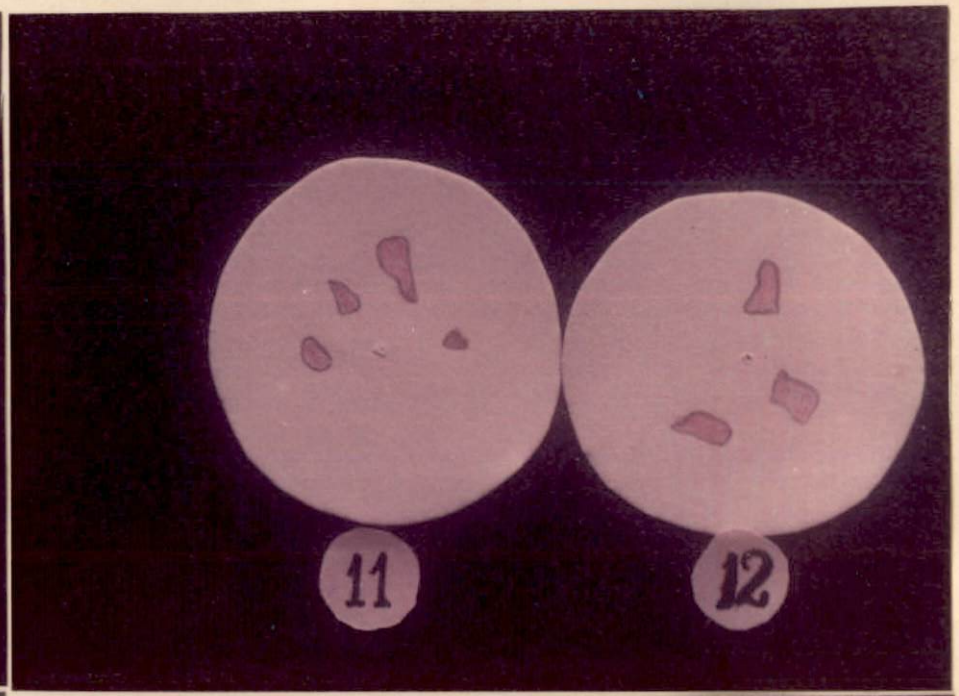
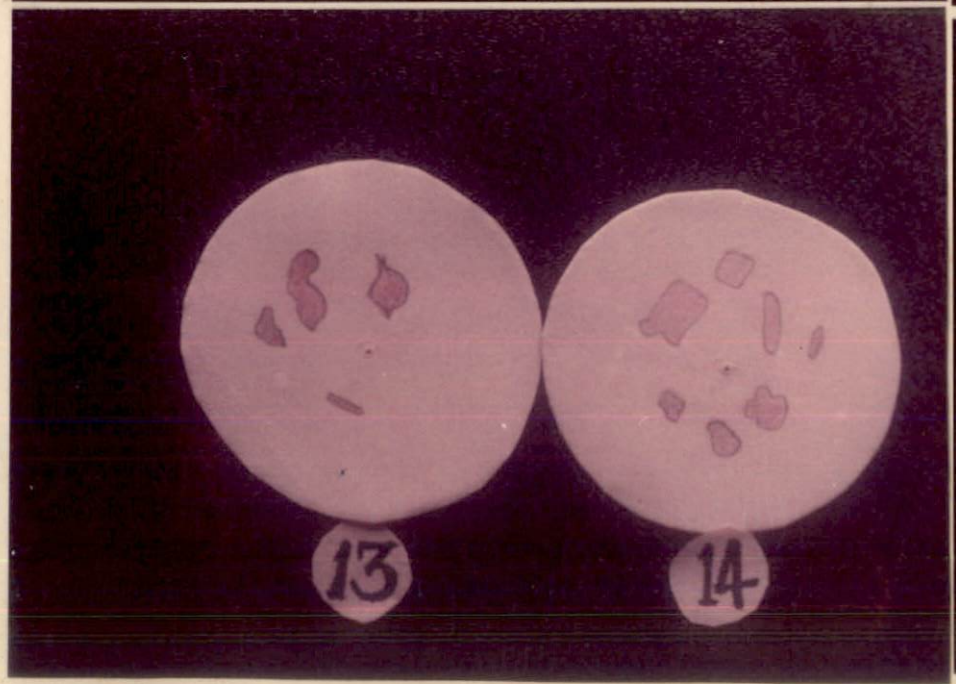

11
12


13
14

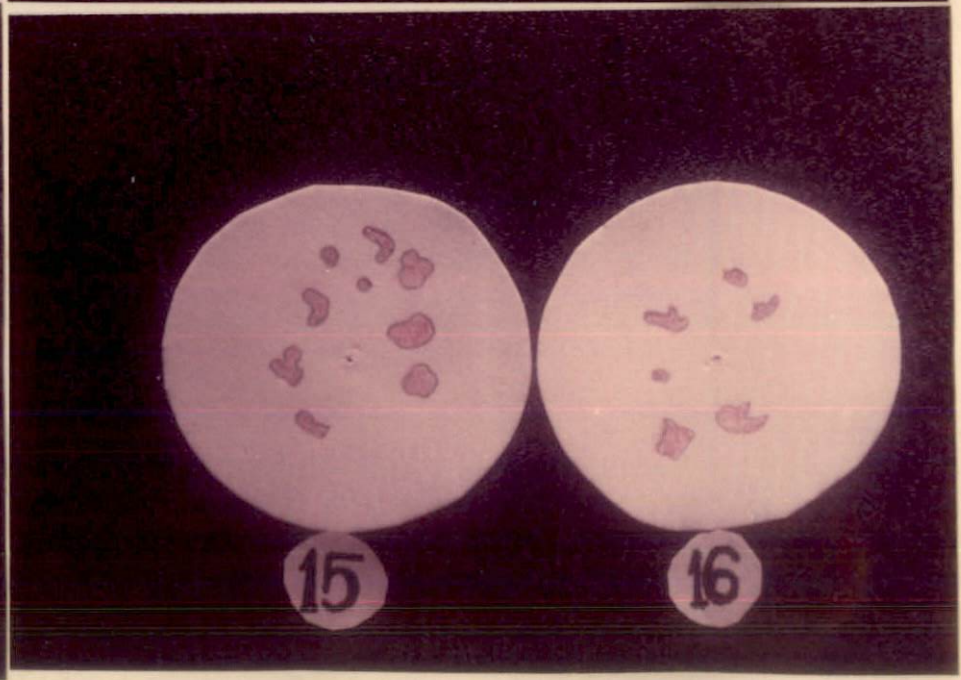
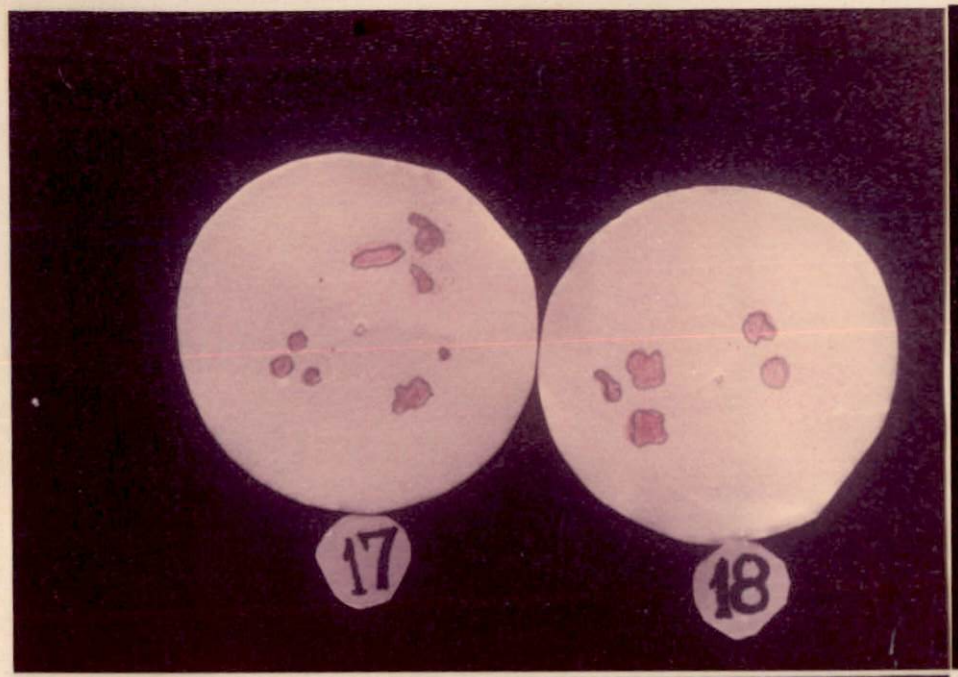

15
16

Figure 9 (contd.)

17. RP 1015-100-25-4
18. KAU 126
19. KAU 153-1
20. KAU 168
21. KAU 93
22. MO 4
23. MO 5
24. MO 6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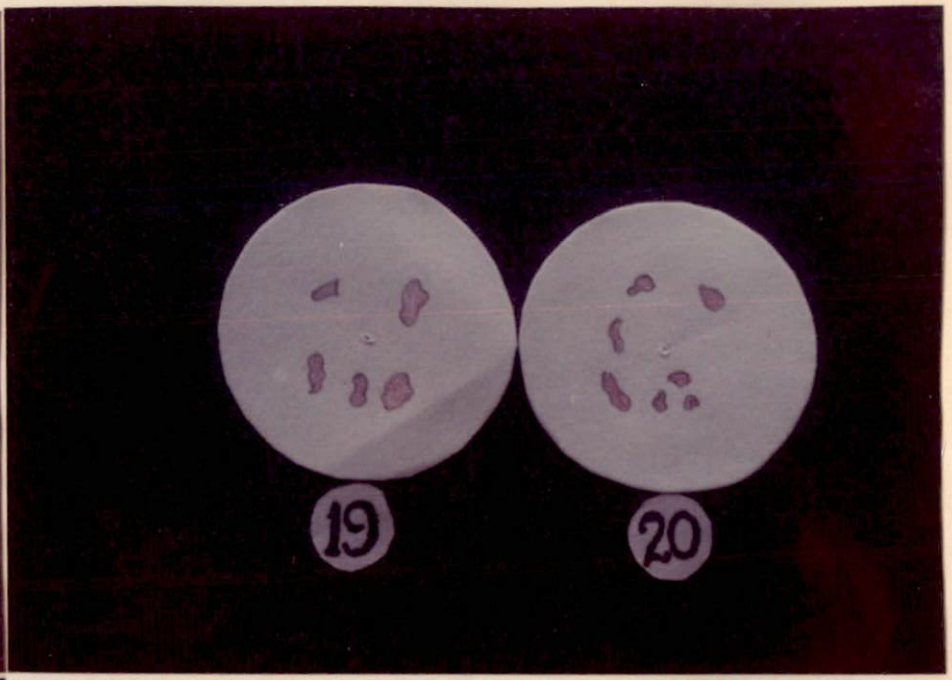
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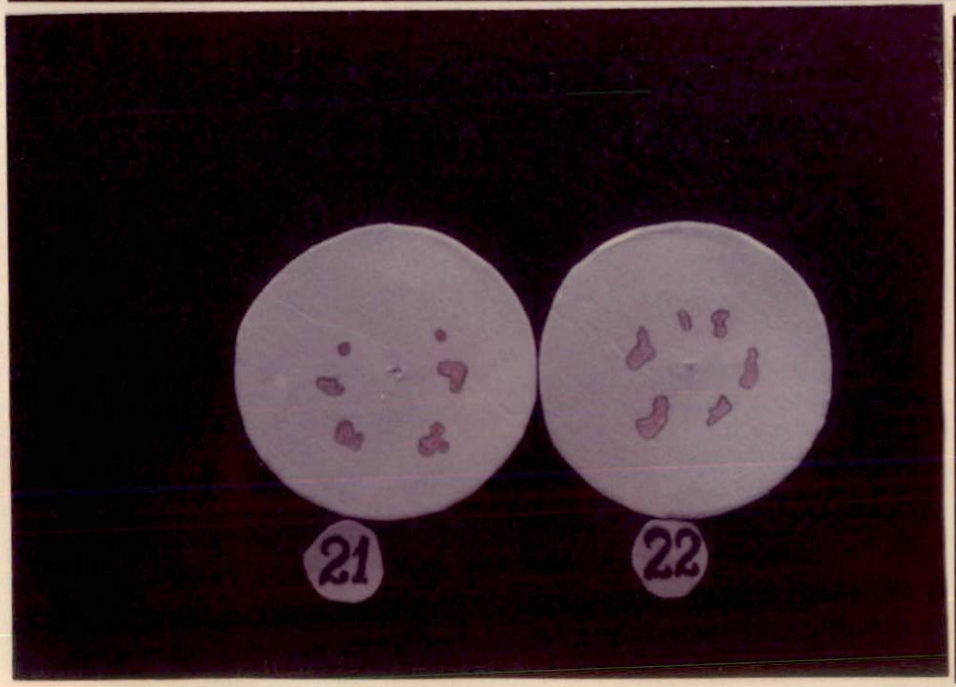
20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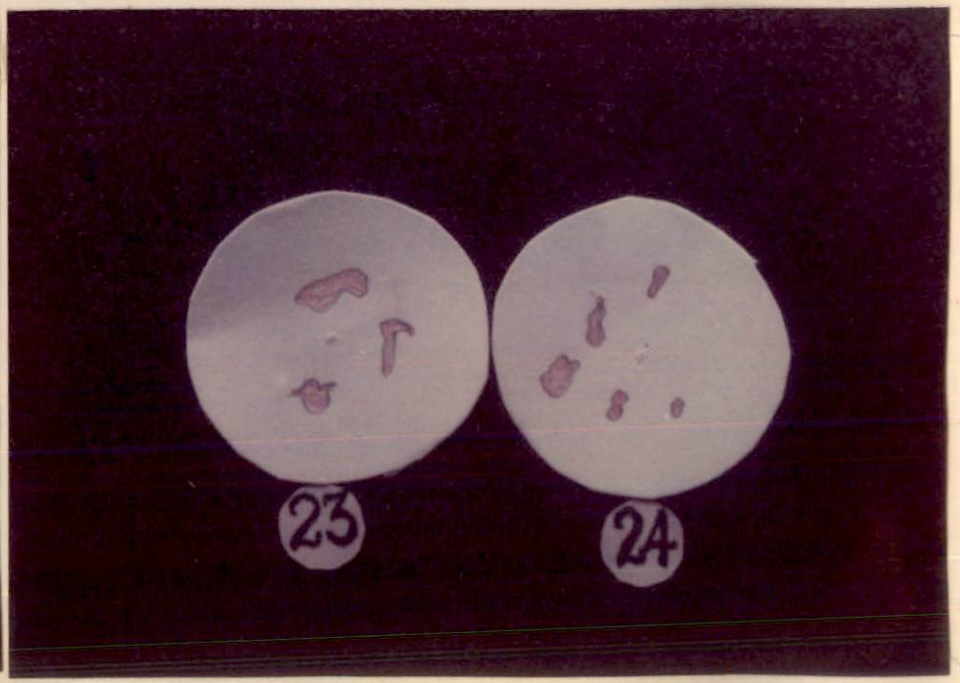
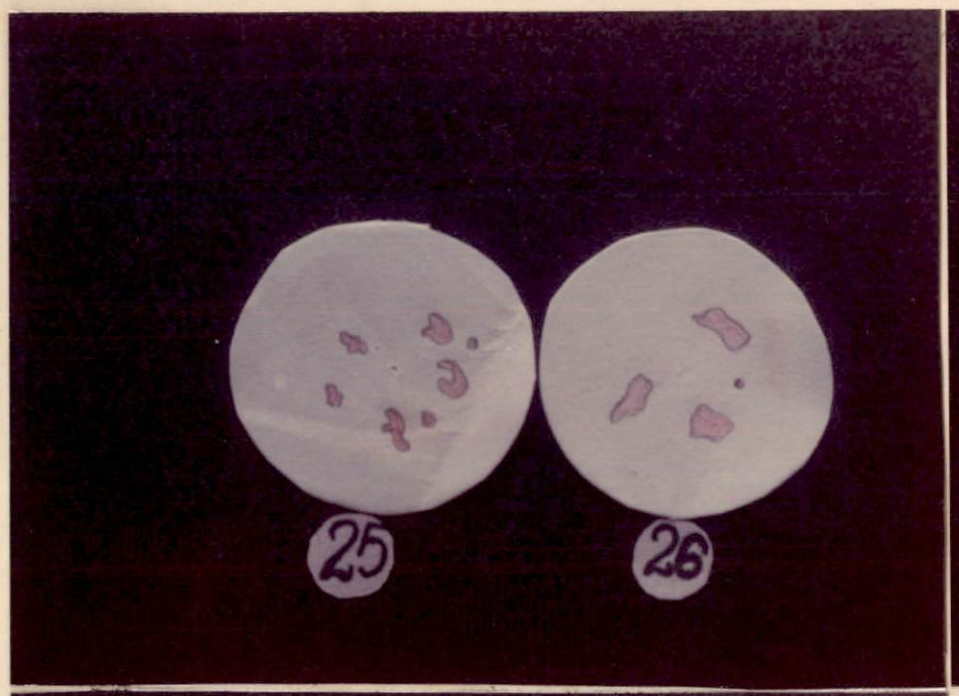

23
24

Figure 9 (contd.)

25. MO 7
26. RP 1015-15-7-72
27. RP 1579-73-1864
28. RP 1579-1863-73-32-53
29. ARC 6650
30. Ptb 33 (Resistant check)
31. M 66 B-45-1
32. TN1 (Susceptible check)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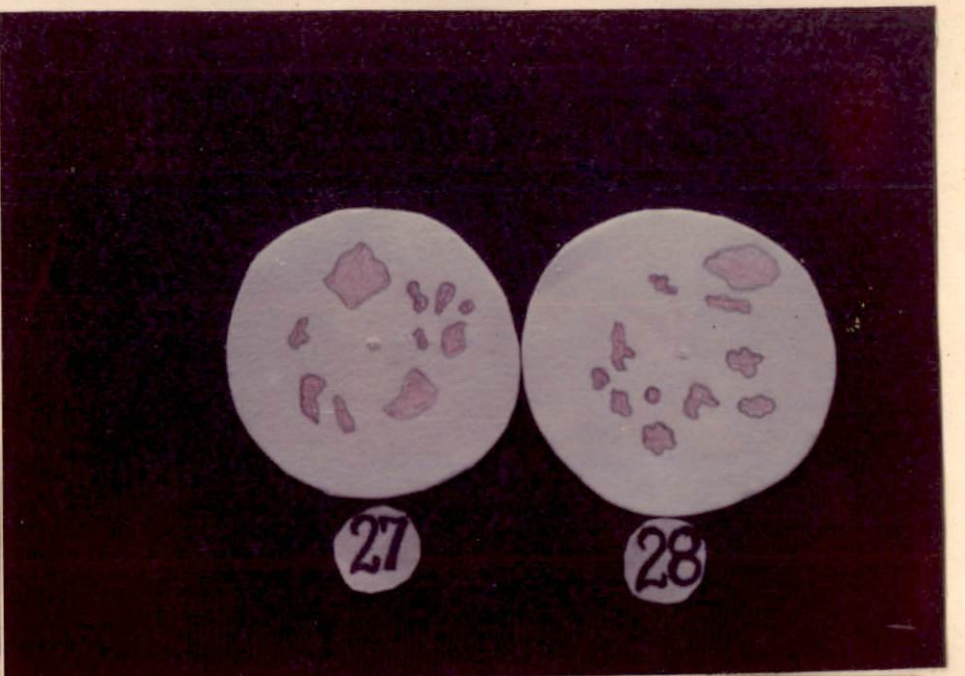
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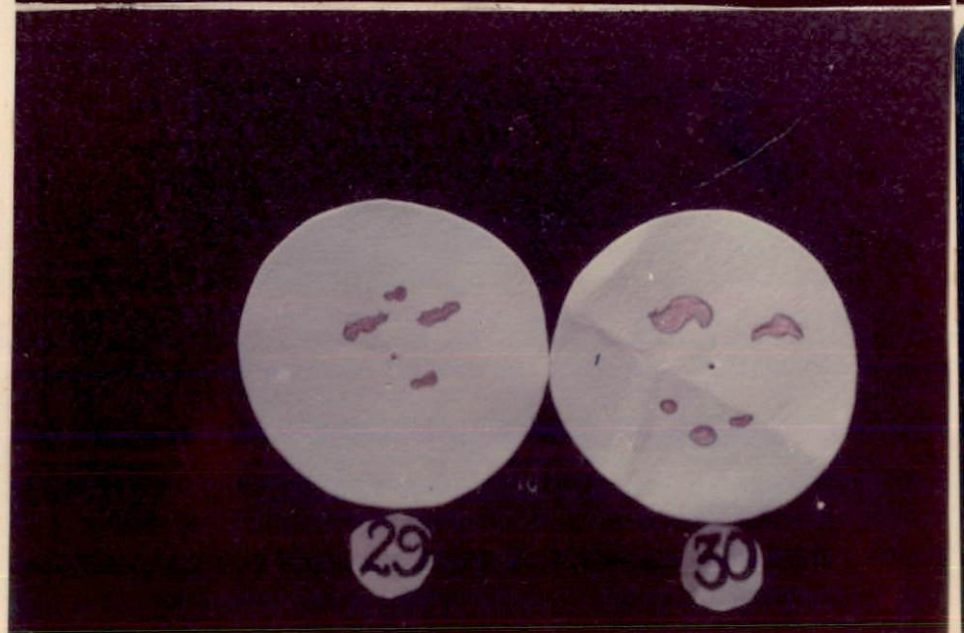
28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30

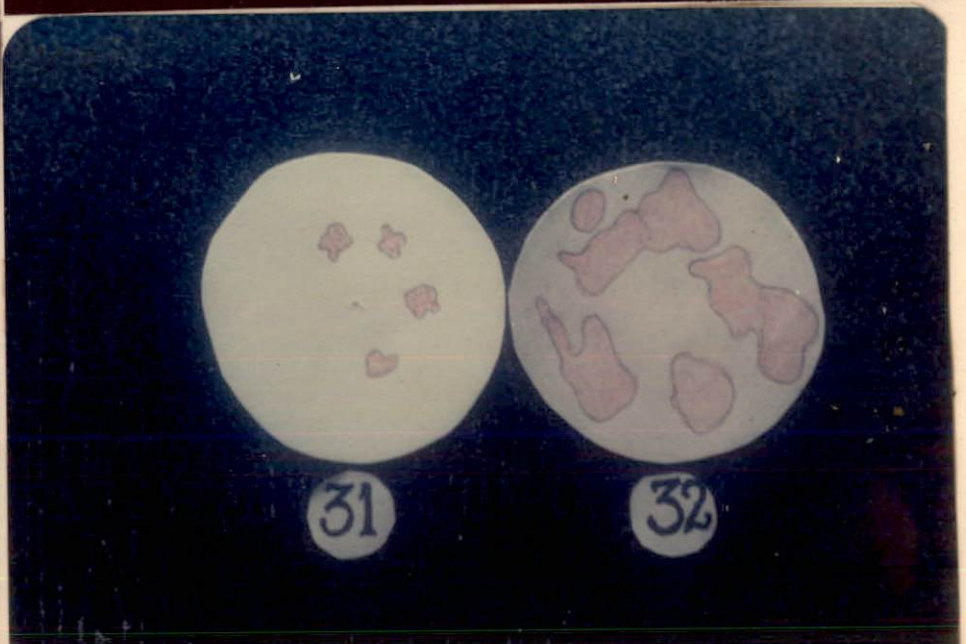

31
32

Table 5 (contd.)

1	2	3	4	5	6
19.	KAU 153-1	1.6	2.3	1.00	R
20.	KAU 168	2.7	1.6	0.95	R
21.	KAU 93	2.2	3.0	0.75	R
22.	Mo 4	2.8	1.6	0.95	R
23.	Mo 5	2.6	2.0	1.00	R
24.	Mo 6	2.0	2.0	0.75	R
25.	Mo 7	2.0	1.6	0.75	R
26.	RP 1015-15-7-72	2.9	2.5	1.01	R
27.	RP 1579-1863-73-32-53	2.8	3.0	2.75	R
28.	ARC 6650	2.9	2.7	0.65	R
29.	Ptb 33 (Resistant check)	2.4	1.6	1.00	R
30.	M 66 B-45-1	1.8	1.2	1.00	R
31.	TN1 (Susceptible check)	8.7	9.0	7.50	HS

R - Resistant

HS - Highly Susceptible

Table 5 BPH score and damage rating of resistant types in the three tests.

Sl. No.	Designation	BPH Damage score		Honey-dew experiment (cm^2)	BPH Damage rating
		Bulk screening test (0-9)	Tiller test (0-9)		
1	2	3	4	5	6
1.	KuruHondarawala	1.2	1.6	1.90	R
2.	IR 40	2.4	2.0	1.02	R
3.	IR 25924-92-1-3	2.5	2.6	0.90	R
4.	IR 1552	1.2	1.3	0.70	R
5.	IR 5741-73-2-3	2.8	1.3	0.64	R
6.	IR 22082-41-2	2.1	2.3	1.50	R
7.	CR 266-407-4	1.2	1.6	0.70	R
8.	RP 2068-32-2-2	1.6	1.6	0.65	R
9.	MTU 5194	1.7	1.6	0.64	R
10.	RP 2695-5-8-31	1.9	2.0	1.36	R
11.	MTU 5295	1.7	1.6	0.75	R
12.	RP 2068-17-2-2	1.6	1.6	1.00	R
13.	RP 1579-56-1907	1.6	1.0	1.00	R
14.	TNAU BPHR 8375	2.4	2.3	2.10	R
15.	MTU 4870	1.6	2.3	1.36	R
16.	RP 1015-45-114-1	1.8	1.3	0.90	R
17.	RP 1015-100-25-4	2.7	2.5	1.05	R
18.	KAU 126	2.6	2.3	1.02	R

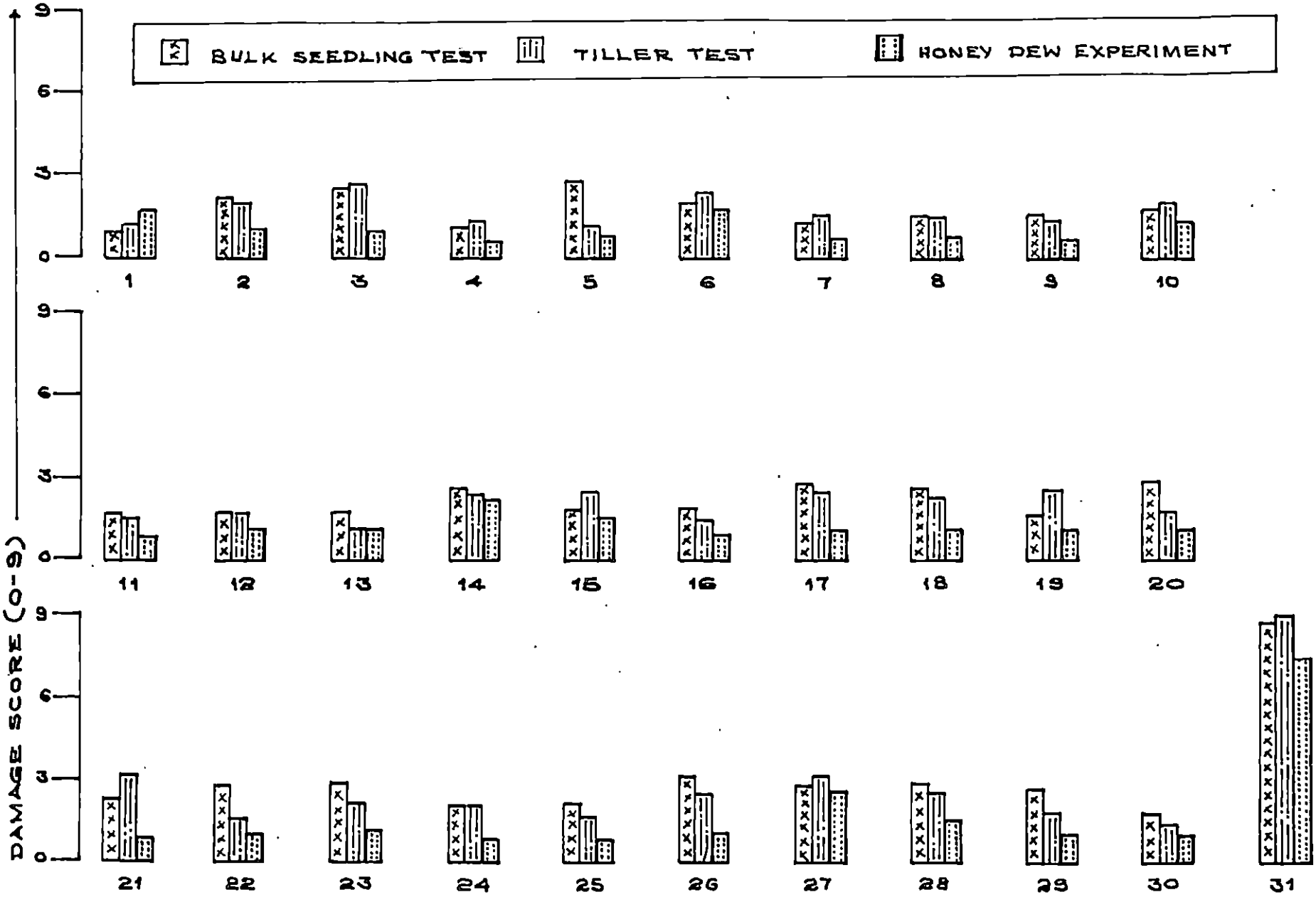

BULK SEEDLING TEST
TILLER TEST
HONEY DEW EXPERIMENT
DAMAGE SCORE (0-9)
0
3
6
9
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

FIGURE.10

Figure 10

Relative damage scores in the three tests

1. KuruHondarawala
2. IR 40
3. IR 25924-92-1-3
4. IR 1552
5. IR 5741-73-2-3
6. IR 22082-41-2
7. CR 266-407-4
8. RP 2068-32-2-2
9. MTU 5194
10. RP 2695-5-8-31
11. MTU 5295
12. RP 2068-17-2-2
13. RP 1579-56-1907
14. TNAU BPHR 8375
15. MTU 4870
16. RP 1015-45-114-1
17. RP 1015-100-25-4
18. KAU 126
19. KAU 153-1
20. KAU 168
21. KAU 93
22. MO 4
23. MO 5
24. MO 6
25. MO 7
26. RP 1015-15-7-72
27. RP 1579-1863-73-32-53
28. ARC 6650
29. Ptb 33 (Resistant check)
30. M 66 B-45-1
31. TN1 (Susceptible check)

Figure 11

Resistant types

1. IR 40
2. MO 4
3. IR 25924-92-1-3
4. IR 5741-73-2-3
5. RP 2695-5-8-31
6. MO 6
7. MO 7
8. M 66 B-45-1

1 2 3 4

5 6 7 8

FIGURE. 11.

Figure 11 (contd.)

9. RP 2068-17-2-2
10. KuruHondarawala
11. RP 2068-32-2-2
12. KAU 126
13. KAU 153-1
14. KAU 93

9 10 11

12 13 14

FIGURE. 11. (CONTD:)

Figure 11 (contd.)

15. MTU 4870

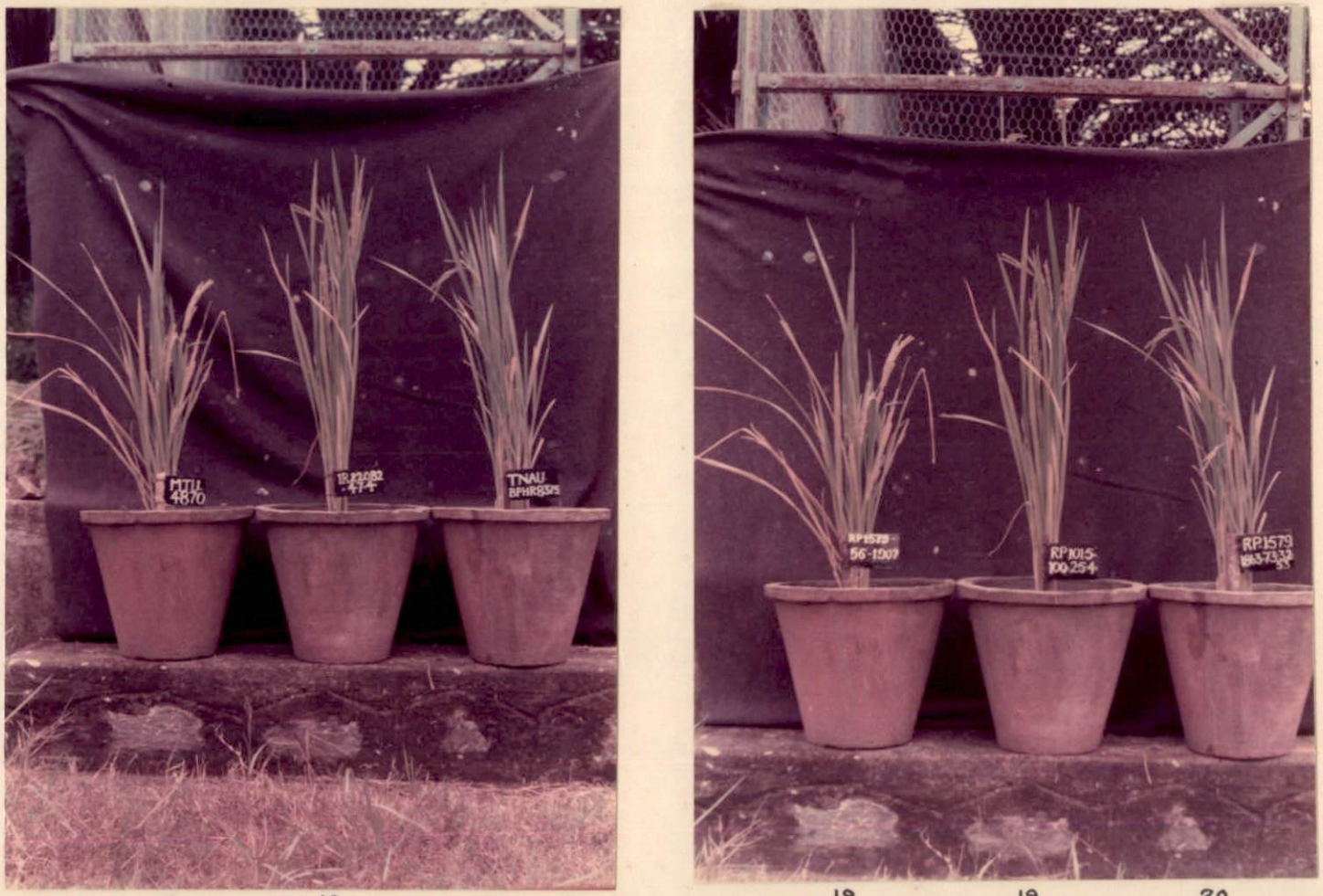
16. IR 22082-41-2

17. TNAU BPHR 8375

18. RP 1579-56-1907

19. RP 1015-100-25-4

20. RP 1579-1863-73-32-53



15 16 17 18 19 20

FIGURE. 11. (CONTD:)

Figure 11 (contd.)

21. MO 5

22. RP 1015-15-7-72

23. KAU 168

24. IR 1552

25. ARC 6650

26. Ptb 33

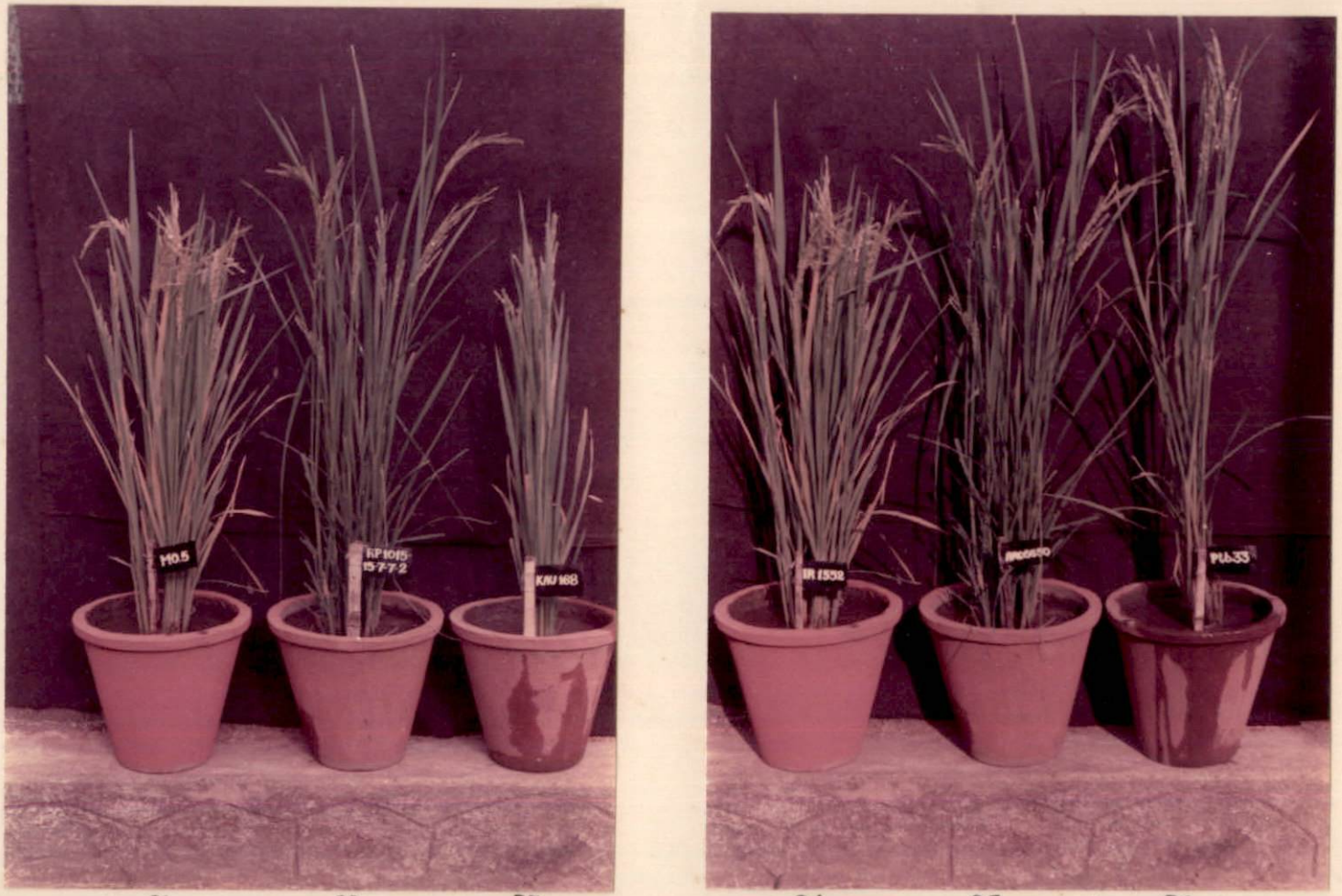


FIGURE. 11. (CONTD:)

Figure 11 (contd.)

27. MTU 5295

28. RP 1015-45-114-1

29. MTU 5194

30. CR 266-407-4

FIGURE. 11. (CONTD:)

MTU 5194 and RP 2068-17-2-2) were from India with characters similar to those of IR 1552. Another type, CR 266-407-4 from India had short duration, nonphotosensitivity, dwarf stature and fine grains. Two other types from India (RP 2695-5-8-31 and MTU 5295) were of medium duration, nonphotosensitivity, dwarf stature and medium bold grains whereas the Indian type RP 1579-56-1907 was of medium duration, nonphotosensitive and semitall with fine grains. Two other types (MO 7 and RP 1015-45-114-1) from India were of short duration, nonphotosensitive, dwarf stature and medium bold grains. Medium duration, nonphotosensitivity, dwarf stature and short bold grains were the features of MO 6 from India. One type was from Indonesia (M 66 B-45-1) with medium duration, nonphotosensitivity, dwarf stature and short bold grains.

The lowest score for honeydew experiment (0.64) was for the type MTU 5194 and the highest score was for the susceptible check TN1 (7.50).

III. Genetic basis of resistance

i) Crossing between resistant and susceptible types

Thirteen types have shown a damage score of less than 2 in all the three screening tests, of which one was from

Sri Lanka, one from Philippines, one from Indonesia and 10 from India. Eight of these which have shown a high level of resistance in bulk seedling test, tiller test and honeydew experiment were selected for genetic analysis based on diverse origin. The details of the selected types are given in Table 6. The variety from Sri Lanka (KuruHondarawala) was photosensitive and hence not selected for genetic analysis. From among the eight selected types, seven were from India and one was from Indonesia (M 66 B-45-1). Among the seven Indian types, one was from Cuttack (CR 266-407-4), two from Andhra Pradesh (MTU 5295 and 5194), two from AICRIP (RP 1015-45-114-1 and RP 2695-5-8-31) and two from Kerala (Mo 6 and 7).

The eight resistant types were crossed as ovule parents with TN1, a dwarf high yielding cultivar from Taiwan, which is highly susceptible to BPH.

The F_1, F_2 and F_3 progenies of the crosses were evaluated for their reaction to BPH to determine the mode of inheritance of resistance. The F_1 seedlings were screened using bulk seedling test, tiller test and honeydew experiment. The F_2 seedlings were screened using bulk seedling test and tiller test. The F_3 seedlings were screened using bulk seedling test only.

Table 6 Designation and other details of resistant types selected for genetic analysis.

Sl. No.	Designation	Parentage	Source	Duration (seed to seed days)	Photo-sensitivity	Stature	Grain type
1.	MTU 5295	MTU 6569 x ARC 6650	India (A.P.)	120	Non sensitive	Dwarf	Medium bold
2.	CR 266-407-4	CR 94-1512-6 x Retna	India (Cuttack)	110	"	"	Short bold
3.	RP 1015-45-114-1	Sona x Manoharsali	India (AICRIP)	110	"	"	Medium bold
4.	MO 6	IR 8 x Karivennel	India (Kerala)	120	"	"	Short bold
5.	MO 7	Triveni x IR 1539	"	110	"	"	Medium bold
6.	M 66 B-45-1	B 4598-PN-132-9-3 x IR 2071-588-56	Indonesia	115	"	"	Short bold
7.	MTU 5194	MTU 6569 x ARC 6650	India (A.P.)	120	"	"	Medium bold
8.	RP 2695-5-8-31	Vikram x Andrewsali	India (AICRIP)	120	"	"	Medium bold

A. Evaluation of the F_1 germination

a) MTU 5295 x TN1

The damage scores and ratings of the parental types and F_1 are given in Table 7. The F_1 was resistant like the resistant parent with score of 1.1, 1.0 and 0.72 for bulk seedling test, tiller test and honeydew experiment respectively. The score values of parental types and F_1 are graphically represented in Figure 12(a). The two parents and the F_1 are shown in Figure 13(a).

b) CR 266-407-4 x TN1

The F_1 of this cross was resistant in all the three screening tests. The data are given in Table 7. The damage scores of resistant parent were 1.2, 1.6 and 0.70 respectively for bulk seedling test, tiller test and honeydew experiment whereas the scores of the F_1 were 1.0, 1.4 and 0.85 and those for the susceptible parent were 9.0, 8.5 and 8.0 respectively. Figure 12(b) represents graphically the three score values of parents and F_1. Figure 13(b) shows the F_1 in comparison to the parents.

c) RP 1015-45-114-1 x TN1

The resistant parent, RP 1015-45-114-1 had score

Table 7 Reaction of types and hybrids to BPH (Resistant x Susceptible crosses).

Cross No.	Varieties and hybrids	Damage score: Bulk seedling test (0-9)	Damage score: Tiller test (0-9)	Honeydew excreted (cm^2)	Damage rating
1	2	3	4	5	6
1.	MTU 5295 x TN1				
	MTU 5295	1.7	1.6	0.75	R
	TN1	8.7	9.0	7.90	HS
	F_1	1.1	1.0	0.72	R
2.	CR 266-407-4 x TN1				
	CR 266-407-4	1.2	1.6	0.70	R
	TN1	9.0	8.5	8.00	HS
	F_1	1.0	1.4	0.85	R
3.	RP 1015-45-114-1 x TN1				
	RP 1015-45-114-1	1.8	1.3	0.90	R
	TN1	7.5	7.9	7.50	HS
	F_1	1.0	0.8	0.75	R
4.	MO 6 x TN1				
	MO 6	2.0	2.0	0.75	R
	TN1	9.0	8.5	8.50	HS
	F_1	1.0	1.0	0.79	R
5.	MO 7 x TN1				
	MO 7	2.0	1.6	0.75	R
	TN1	9.0	9.0	7.90	HS
	F_1	1.2	1.1	0.82	R

Table 7 (contd.)

1	2	3	4	5	6
6.	M66 B-45-1 x TN1				
	M66 B-45-1	1.8	1.2	1.00	R
	TN1	8.9	9.0	8.70	HS
	F_1	1.0	1.1	0.95	R
7.	MTU 5194 x TN1				
	MTU 5194	1.7	1.6	0.64	R
	TN1	7.7	7.0	7.75	HS
	F_1	1.0	1.1	0.70	R
8.	RP 2695-5-8-31 x TN1				
	RP 2695-5-8-31	1.9	2.0	1.36	R
	TN1	9.0	9.0	8.20	HS
	F_1	1.2	1.8	0.95	R

R - Resistant

HS - Highly Susceptible

S - Susceptible

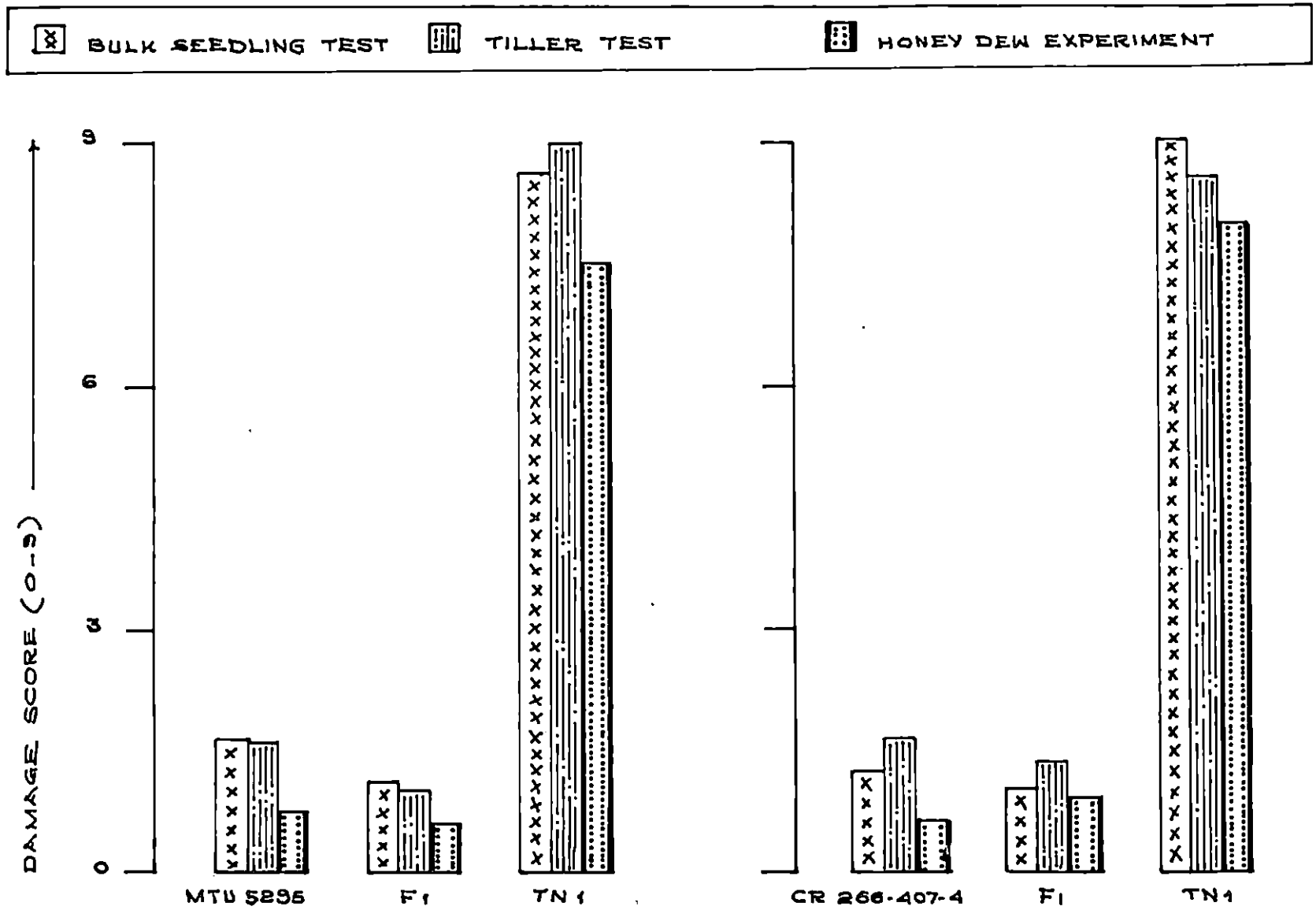


FIGURE.12a.

FIGURE.12 b.

Figure 13

Varieties and F_1 in Resistant x Susceptible Crosses

a. MTU 5295 x TN1

b. CR 266-407-4 x TN1

a. b.

FIGURE. 13.

values of 1.8, 1.3 and 0.9 respectively for bulk seedling test, tiller test and honeydew experiment and TN1, the susceptible parent had score values of 7.5, 7.9 and 7.5. Like the resistant parent, the F_1s were resistant in all the screening tests with score values of 1.0, 0.8 and 0.75 respectively. The data of BPH score and damage rating of parental types and the F_1 are given in Table 7. Figure 12(c) represents graphically the score values in the three tests of parental varieties and the F_1. The parents and F_1 are shown in Figure 13(c).

d) MO 6 x TN1

MO 6, the resistant parent in this cross had score values of 2.0, 2.0 and 0.75 respectively for bulk seedling test, tiller test and honeydew experiment whereas TN1 gave 9.0, 8.5 and 8.5 as score values. The F_1s gave 1.0, 1.0 and 0.79 score values for bulk seedling test, tiller test and honeydew experiment respectively. These score values indicate that the F_1s were similar to the resistant parent MO 6 in respect of resistance. The score values for the three screening tests and the damage ratings are presented in Table 7. Figure 12(d) represents the score values of parents and the F_1. Figure 13(d) shows MO 6, TN1 and the F_1.

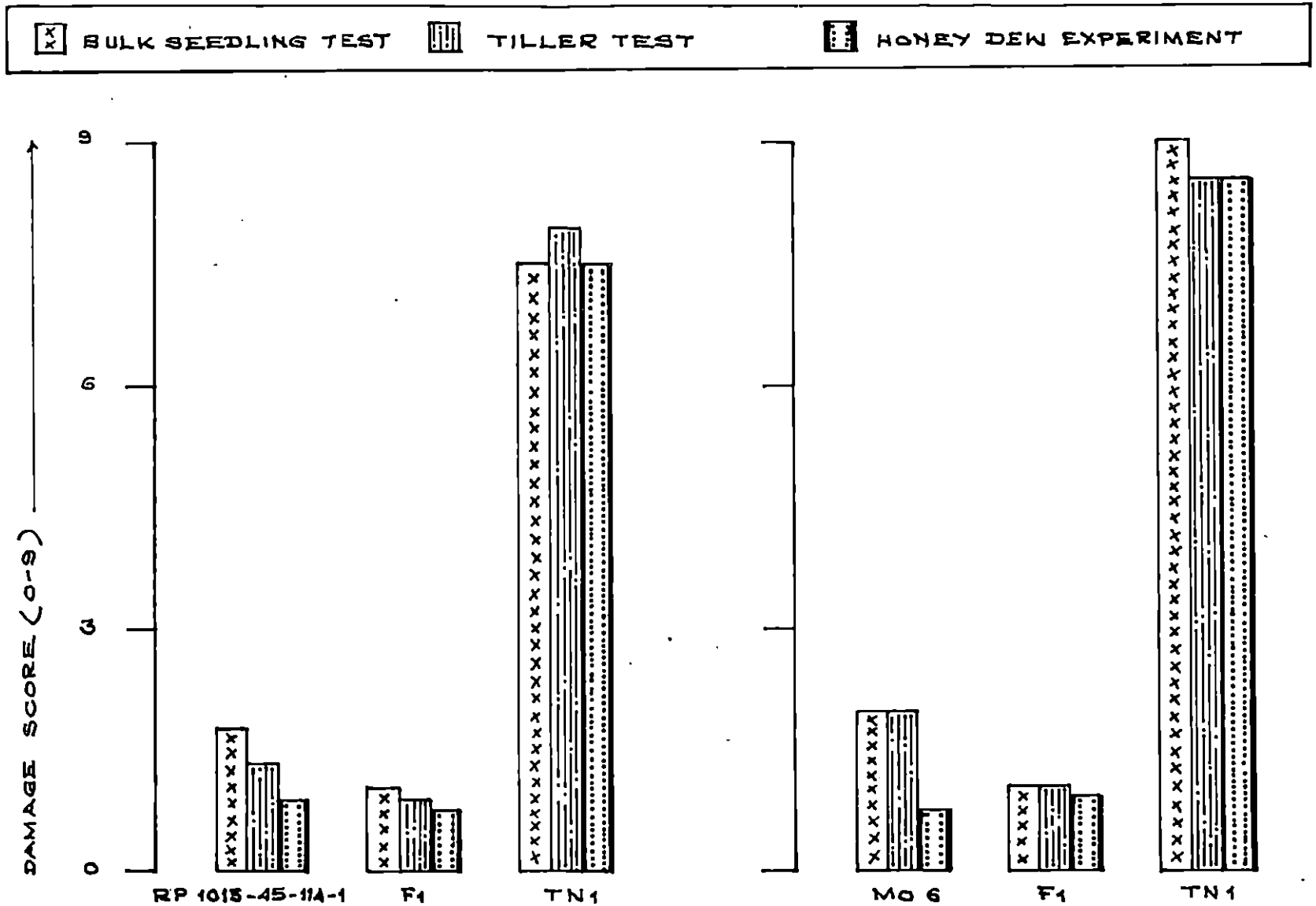


FIGURE. 12 C.

FIGURE. 12 d.

Figure 13 (contd.)

c. RP 1015-45-114-1 x TN1

d. MO 6 x TN1

c.

d.

FIGURE. 13. (CONTD;)

e) MO 7 x TN1

The resistant type MO 7 had score values of 2.0, 1.6 and 0.75 in bulk seedling test, tiller test and honeydew experiment respectively. Like the resistant parent, the F_1s also showed resistance in all the three screening tests with scores of 1.2, 1.1 and 0.82 respectively. The susceptible check TN1 scored 9.0, 9.0 and 7.90 in the three tests. Figure 12(e) represents the scores of the parents and F_1 and Figure 13(e) shows the parents and F_1. The score values of parents and the F_1 are recorded in Table 7.

f) M 66 B-45-1 x TN1

The F_1s of the cross M 66 B-45-1 x TN1 showed resistance like the resistant parent M 66 B-45-1 in all the three screening tests. The score values for M 66 B-45-1 were 1.8, 1.2 and 1.00 respectively for bulk screening test, tiller test and honeydew experiment. The score values for F_1 were 1.0, 1.1 and 0.95 in the three screening tests respectively. The score values of susceptible parent TN1 were 8.9, 9.0, 8.7. The score values of parents and F_1 are given in Table 7. Figure 12(f) shows graphically the scores of the parents and F_1 and Figure 13(f) shows the parents along with the F_1.

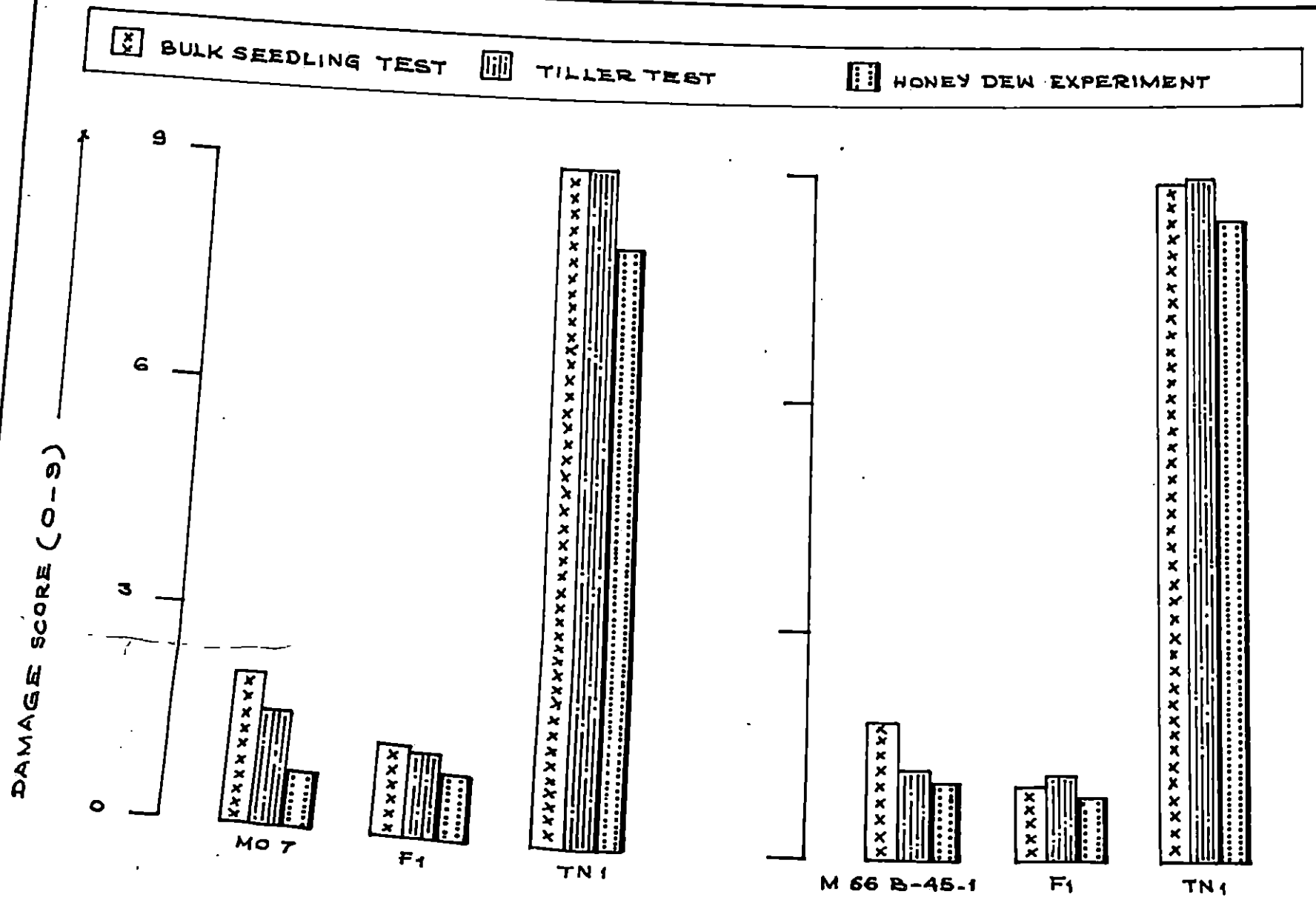


FIGURE. 12e.

FIGURE. 12f.

Figure 13 (contd.)

e. MO 7 x TN1

f. M 66 B-45-1 x TN1

e.

f.

FIGURE. 13. (CONTD)

g.

h.

FIGURE. 13. (CONTD:)

g) MTU 5194 x TN1

The F_1 seedlings were resistant like the resistant parent MTU 5194. The score values of F_1 and parents are presented in Table 7. For bulk seedling test, the resistant parent MTU 5194 scored 1.7 and the score of the F_1 was 1.0. For tiller test the scores were 1.6 and 1.1 and for honeydew experiment the values were 0.64 and 0.70 respectively. The susceptible parent TN1 scored 7.7, 7.0 and 7.75 respectively for bulk seedling test, tiller test and honeydew experiment. The Figure 12(g) represents graphically the score values of the three tests of parents and F_1. Figure 13(g) shows the parents and the F_1.

h) RP 2695-5-8-31 x TN1

The F_1s of this cross showed resistance. They resembled the resistant parent RP 2695-5-8-31 in all the screening tests. The score values of RP 2695-5-8-31 were 1.9, 2.0 and 1.36 for bulk seedling test, tiller test and honeydew experiment respectively whereas the respective F_1 scores were 1.2, 1.8 and 0.95. The score values for the susceptible parent TN1 were 9.0, 9.0 and 8.20 respectively. The score values of the parents and F_1 for the three screening tests are given in Table 7. Figure 12(h) represents

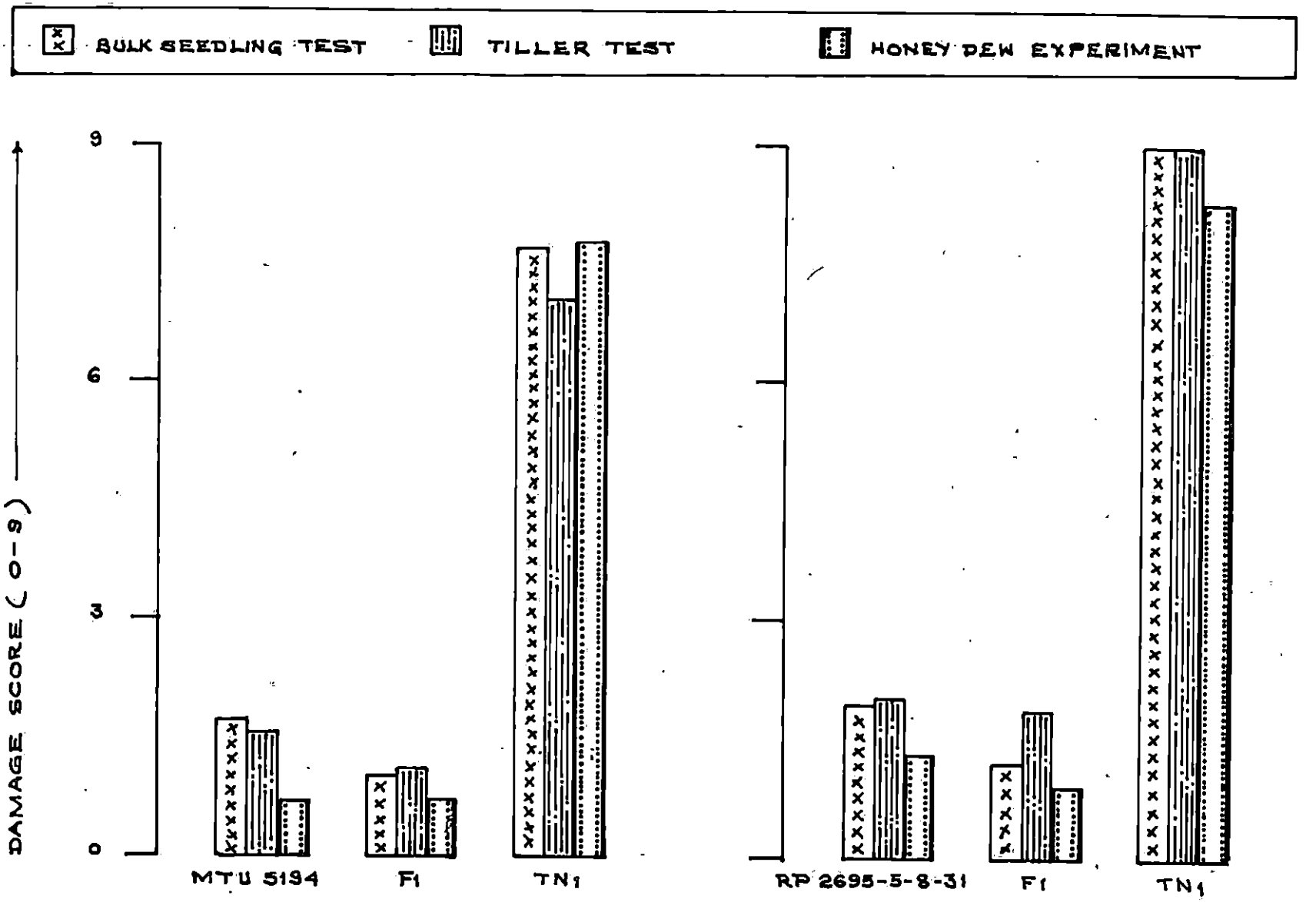


FIGURE. 12 g.

FIGURE. 12 h.

Figure 13 (contd.)

g. MTU 5194 x TN1

h. RP 2695-5-8-31 x TN1

graphically the score values of the parents and F_1. Figure 13(h) shows the parents and the F_1.

B. Evaluation of the F_2 populations

a) MTU 5295 x TN1

The F_2 population of the cross MTU 5295 x TN1 showed segregation into resistant and susceptible types. The F_2 seedlings were screened using bulk seedling test and tiller test. Two hundred and fiftythree seedlings were screened, of which 186 were resistant in both the tests. 67 have shown susceptibility. The observed frequencies showed a good fit to a 3:1 model with high probability. The segregation pattern of F_2 seedlings is presented in the Table 8. The distribution of score values of F_2 seedlings in bulk seedling test are presented in Figure 14(a).

b) CR 266-407-4 x TN1

In the F_2 population, a total of 530 seedlings were screened using bulk seedling test and tiller test. Unlike the F_1, the scores in the F_2 population varied from 0 to 9. There were 398 resistant seedlings and 132 susceptible seedlings. The χ^2 analysis revealed that there was a very good fit to a 3:1 ratio for resistance and susceptibility. The

Table 8 Segregation for resistance to BPH in the F_2 populations (Resistant x Susceptible cross.

Cross No.	Cross combination	Bulk seedling test BPH damage score						Total no. of seedlings screened	No. of resistant seedlings		No. of susceptible seedlings	Percentage of susceptible seedlings	χ^2 value (3:1)
		0	1	3	5	7	9		Bulk seedling test	Tiller test*			
1.	MTU 5295 x TN1	53	86	47	0	11	56	253	186	186	67	26.48	0.2964
2.	CR 266-407-4 x TN1	123	192	83	0	25	107	530	398	398	132	24.90	0.0025
3.	RP 1015-45-114-1 x TN1	114	60	28	0	14	50	266	202	202	64	24.09	0.3759
4.	MO 6 x TN1	101	52	22	0	20	41	236	175	175	61	25.80	0.2712
5.	MO 7 x TN1	50	82	74	0	18	52	276	206	206	70	25.45	0.0193
6.	M 66 B-45-1 x TN1	87	62	37	0	12	50	248	186	186	62	25.00	0
7.	MTU 5194 x TN1	109	184	73	0	7	128	501	366	366	135	26.94	1.0120
8.	RP 2695-5-8-31 x TN1	72	40	49	0	15	40	216	161	161	55	25.46	0.0247

* Computed value

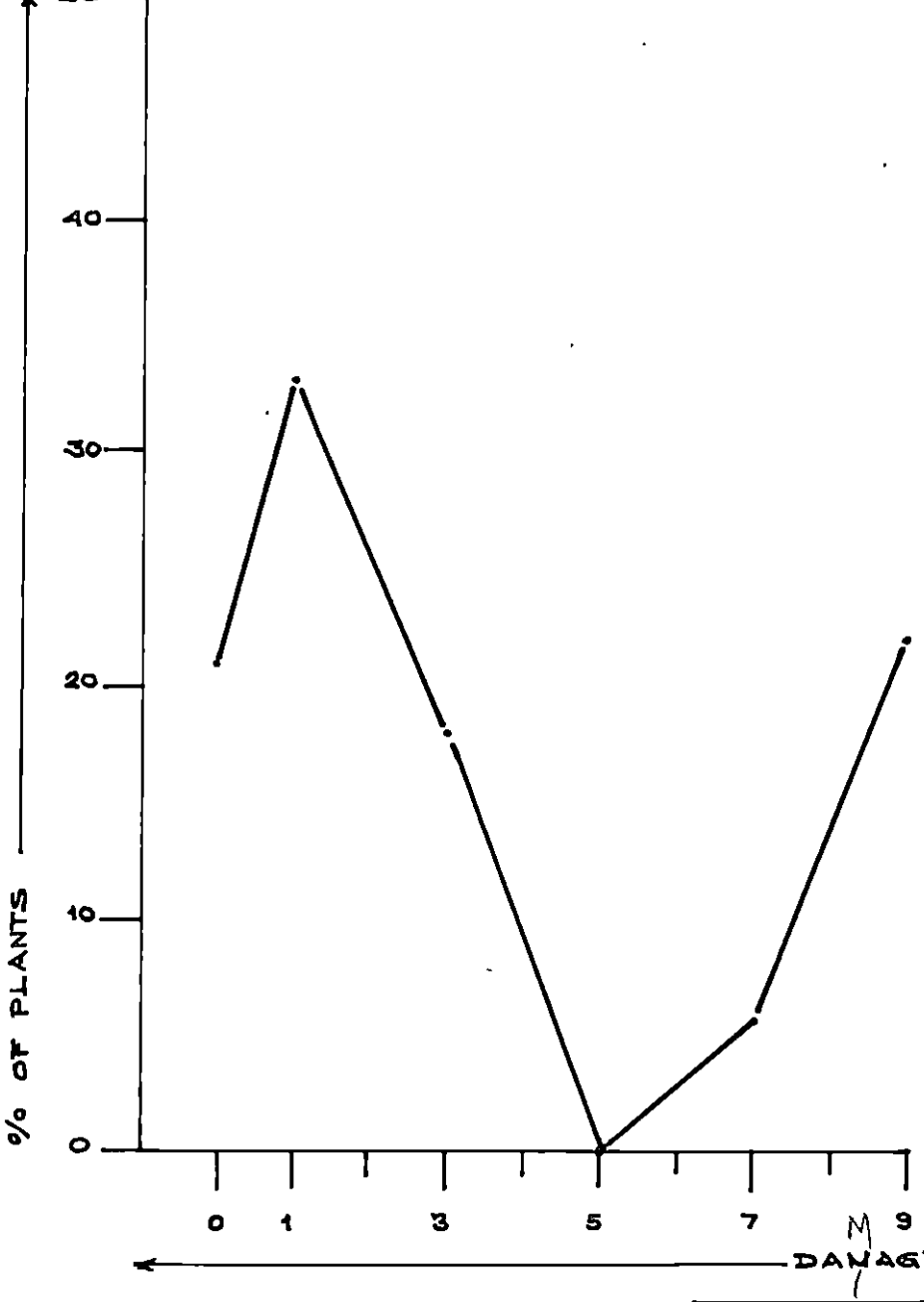


FIGURE. 14 a.

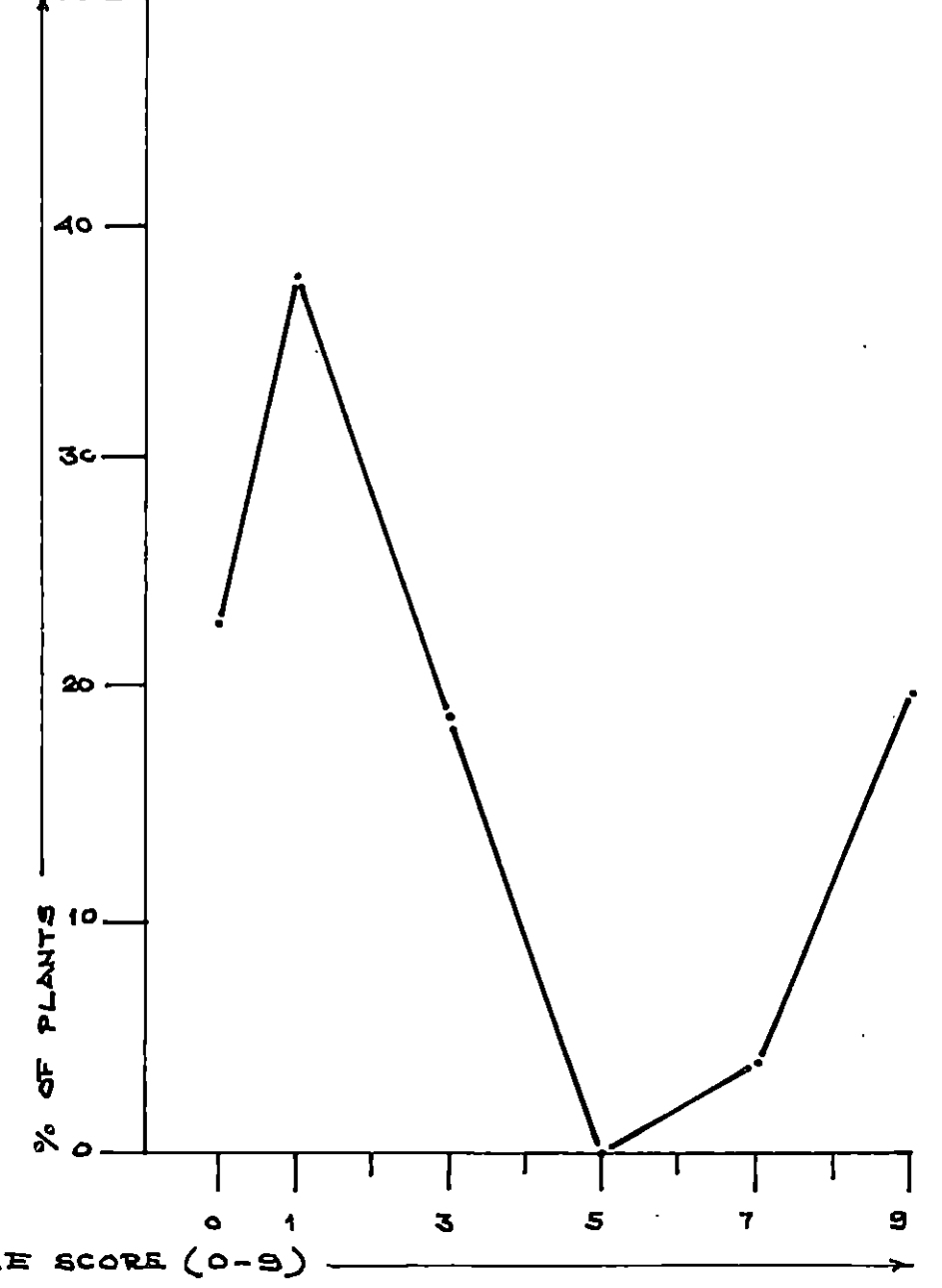


FIGURE. 14 b.

data showing segregation of F_2 population are presented in Table 8. The score values of the seedlings in bulk seedling test are graphically represented in Figure 14(b).

c) RP 1015-45-114-1 x TN1

The F_2 population segregated into resistant and susceptible types. The data on segregation of F_2 seedlings are presented in Table 8. The seedlings were screened using bulk seedling test and tiller test. Out of 266 seedlings screened, 202 were resistant and 64 were susceptible. The observed frequency showed a good fit to the 3:1 expected frequency with high probability. The score values of F_2 seedlings are graphically represented in Figure 14(c).

d) MO 6 x TN1

In the F_2 population, 236 seedlings were screened using bulk seedling test and tiller test. One hundred and seventyfive seedlings were resistant and 61 were susceptible. The data showing segregation of seedlings for resistance are presented in Table 8. Statistical analysis of the F_2 segregation showed good fit to 3:1 ratio for resistant and susceptible seedlings. The score values varied from 0 to 3 for resistant seedlings and that for susceptible seedlings varied from 7 to 9. Moderately resistant seedlings were

Figure 14 (contd.)

c. RP 1015-45-114-1 x TN1

d. MO 6 x TN1

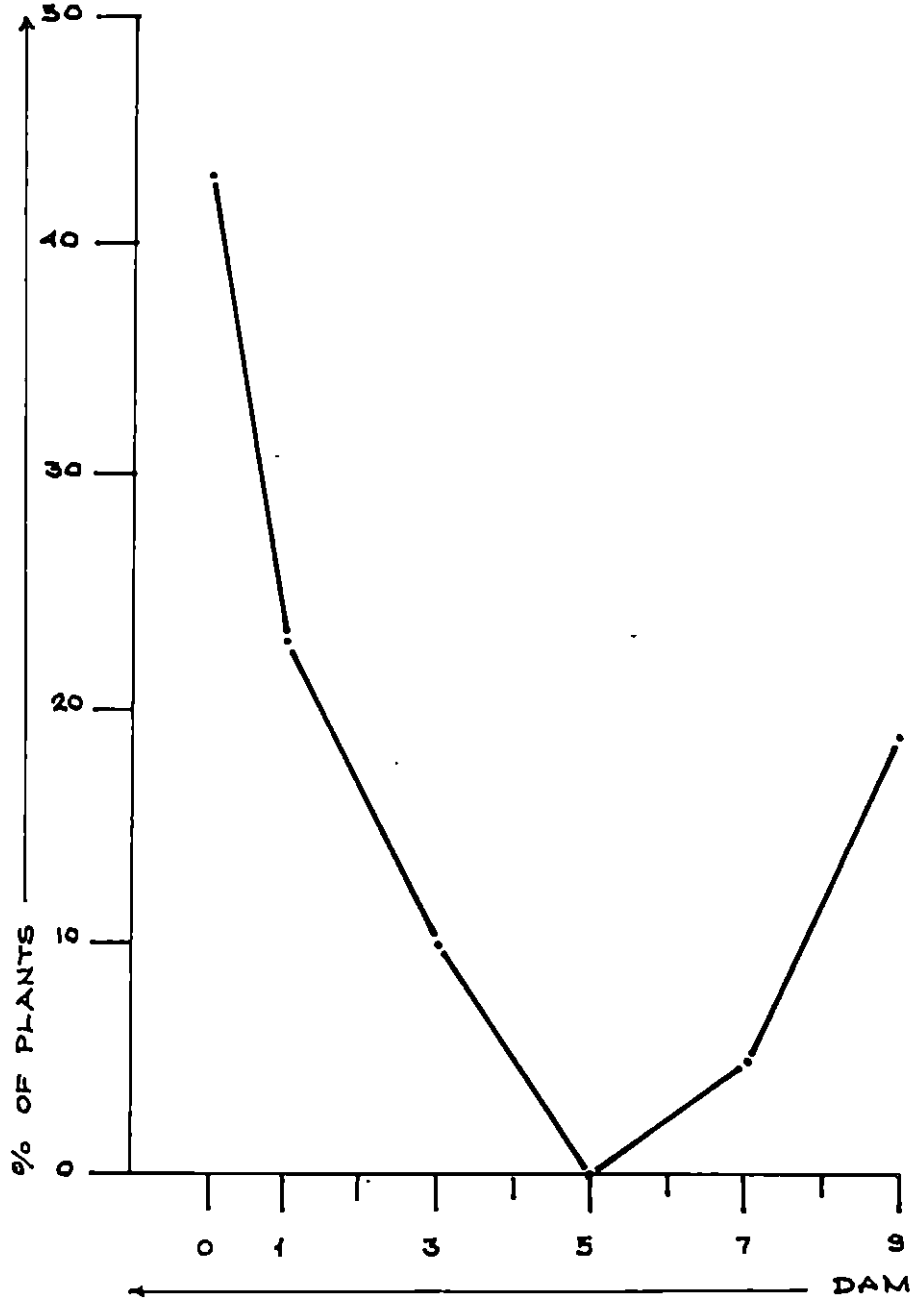


FIGURE. 14 C.

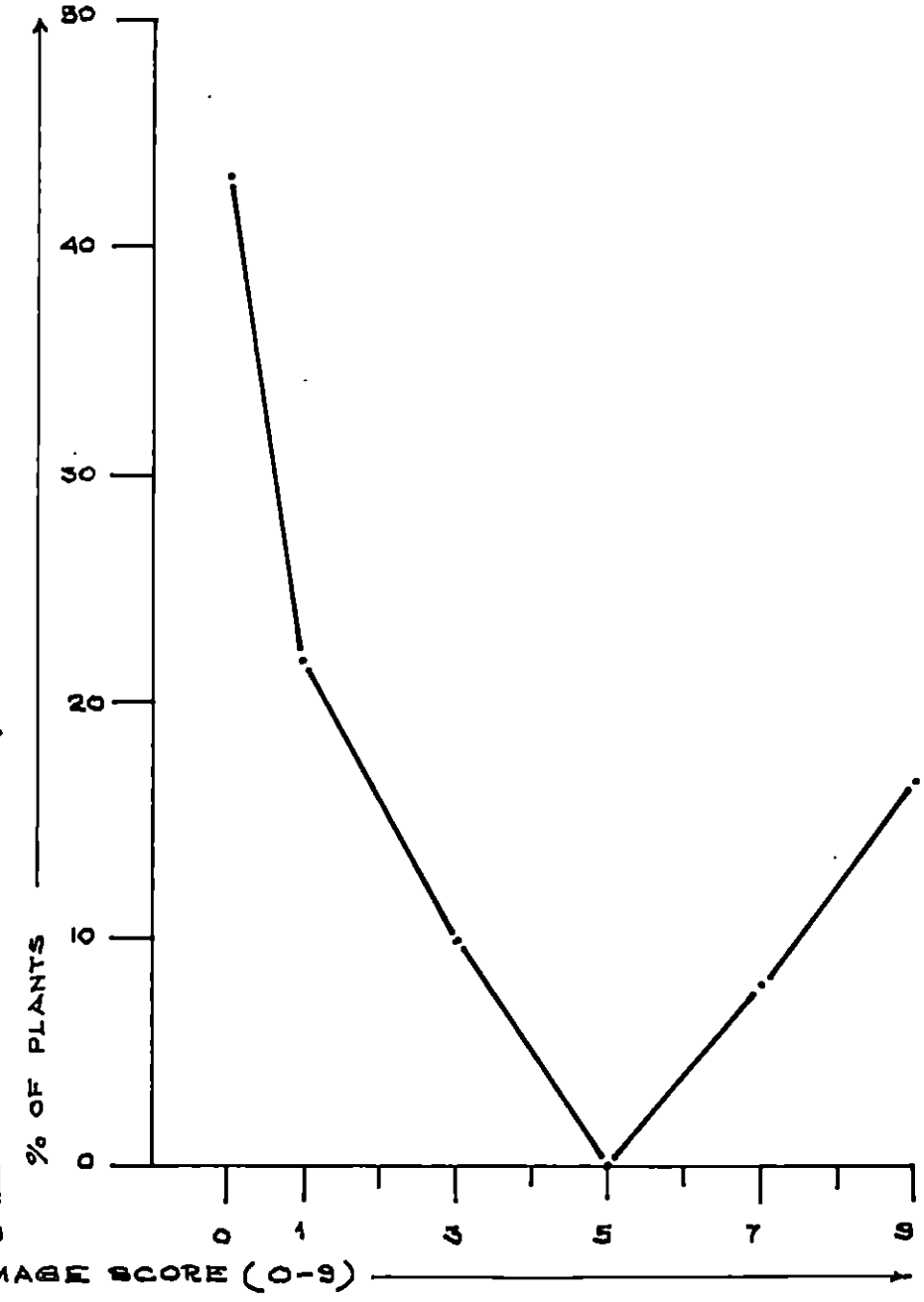


FIGURE. 14 d.

totally absent. The score values of bulk seedling test of F_2 population are presented in Figure 14(d).

e) MO 7 x TN1

The F_2 population consisted of 276 seedlings out of which 206 were resistant and 70 were susceptible. The pattern of segregation indicated a 3 resistant:1 susceptible ratio. Analysis of the observed frequencies showed satisfactory fit to the 3:1 ratio. The seedlings were scored by bulk seedling test and tiller test. The data on segregation are presented in Table 8. The score values of the seedlings in bulk seedling test are presented in Figure 14(e).

f) M66 B-45-1 x TN1

The F_2 population of this cross also segregated into resistant and susceptible types. The scores for resistance were from 0 to 3 and those for susceptibility ranged from 7 to 9. Out of the 248 seedlings screened, 186 were resistant and 62 were susceptible. The data on segregation pattern are presented in Table 8. Observed ratio of segregation pattern was 3:1 for resistance and susceptibility. X^2 analysis revealed that there is a perfect fit to the observed ratio of 3:1. The score values are represented by Figure 14(f).

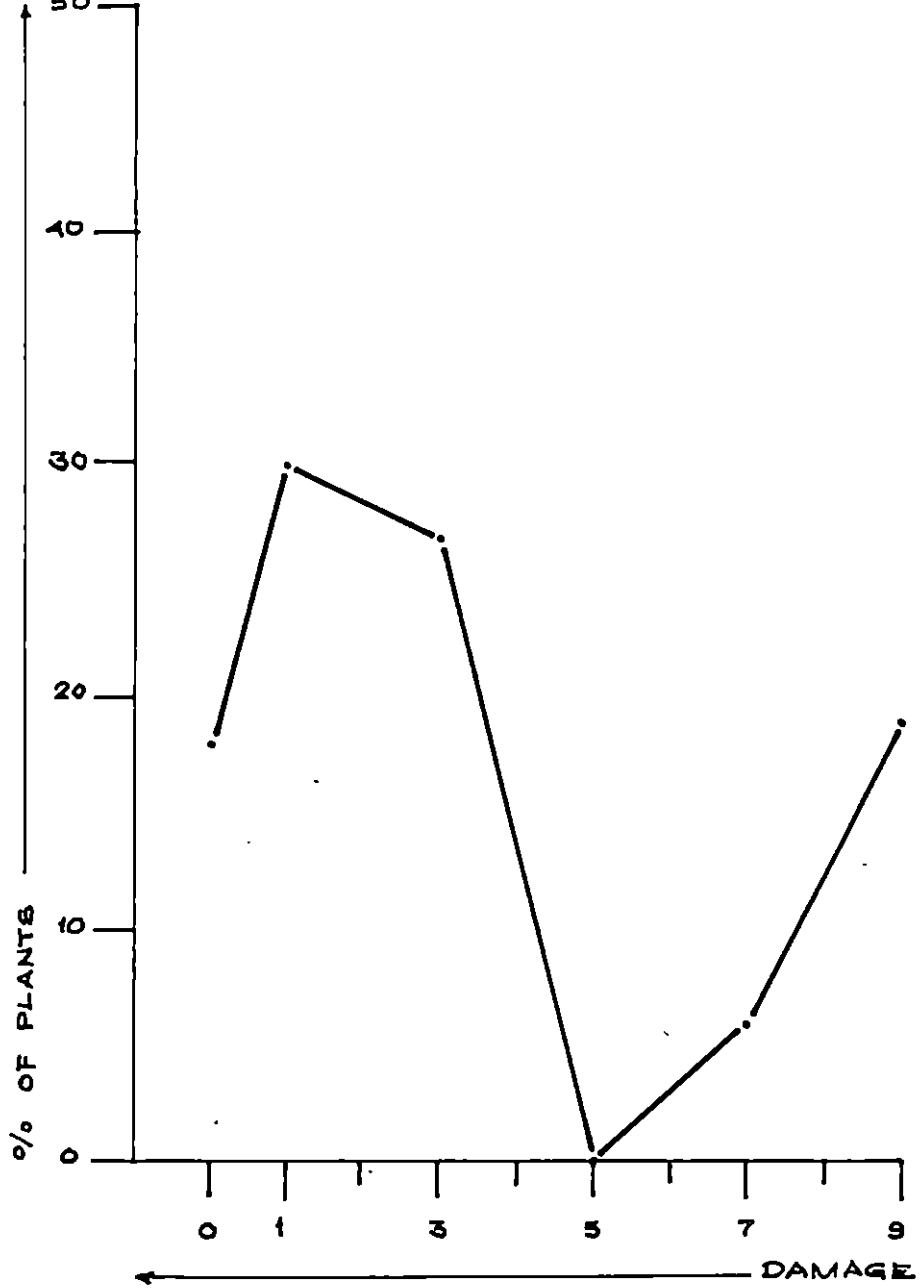


FIGURE. 14 e.

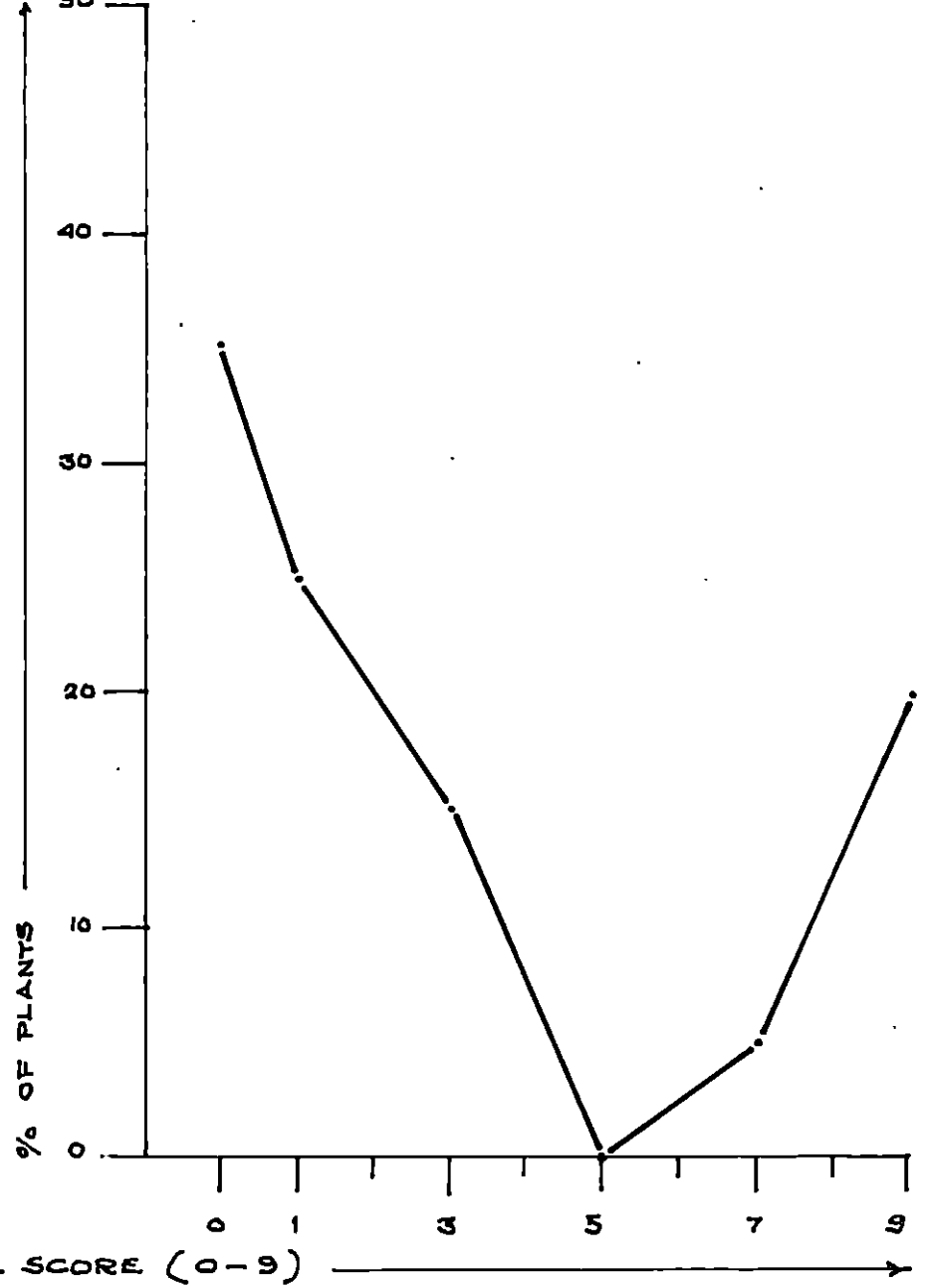


FIGURE. 14 f.

g) MTU 5194 x TN1

The F_2 population of the cross showed segregation for resistance and susceptibility. A total number of 501 seedlings were screened by bulk seedling test and tiller test. 366 seedlings were resistant with scores in between 0 and 3. 135 seedlings were susceptible with scores ranging from 7 to 9. The data on segregation are recorded in Table 8. The score values of F_2 seedlings in bulk seedling test are shown in Figure 14(g). The frequencies of the segregating population gave a satisfactory fit into 3 resistant: 1 susceptible ratio.

h) RP 2695-5-8-31 x TN1

The F_2 population consisted of 216 seedlings out of which 161 were resistant with scores ranging from 0 to 3 and the remaining 55 were susceptible with scores ranging from 7 to 9. The data on segregation are given in Table 8. The score values of F_2 seedlings of bulk seedling test are shown in Figure 14(h). X^2 analysis revealed that there was a good fit for the observed ratio to the expected 3:1 with high probability.

C. Evaluation of F_3 seedlings

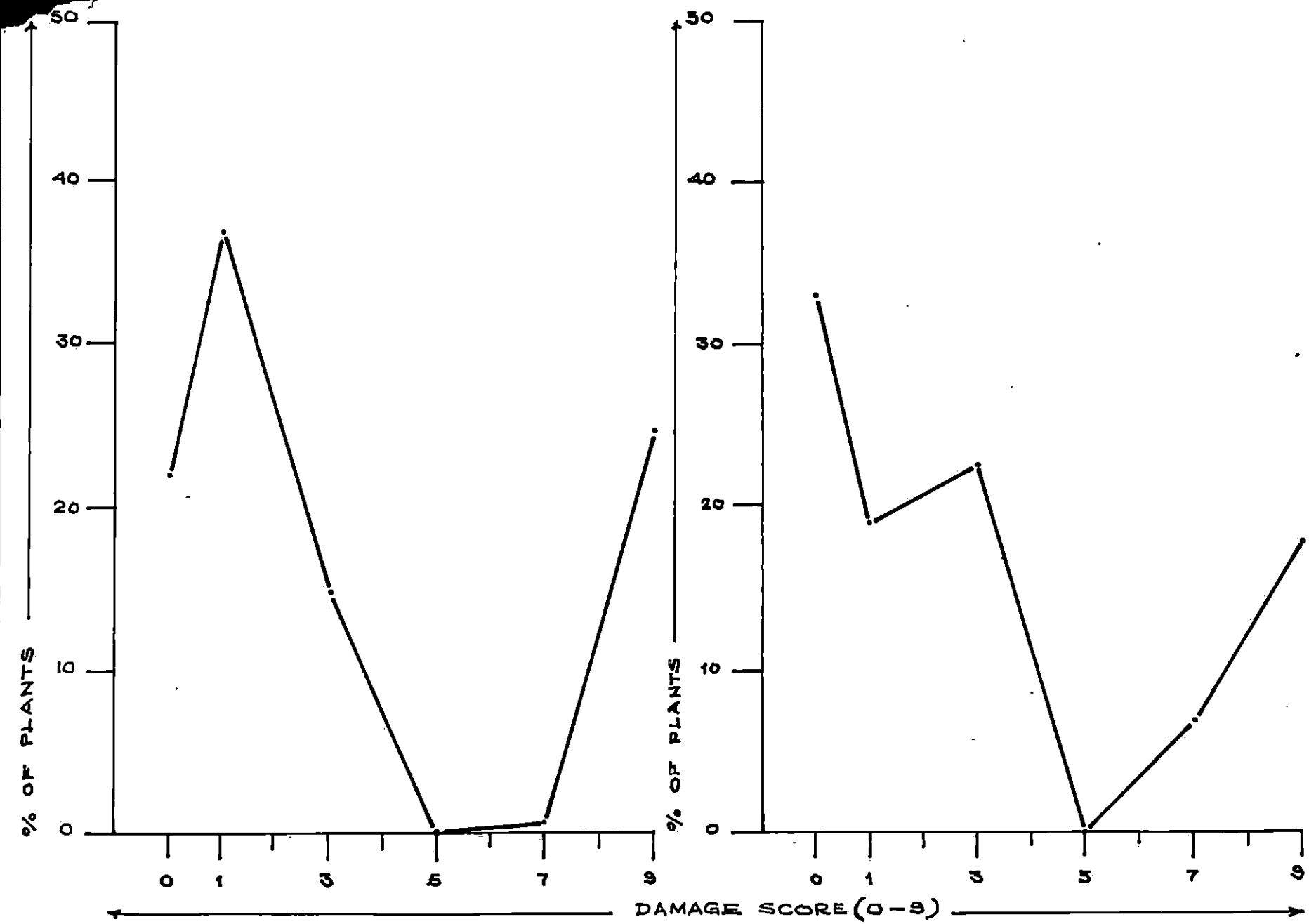
a) MTU 5295 x TN1

The F_2 results were verified by classifying the F_3

Figure 14 (contd.)

g. MTU 5194 x TN1

h. RP 2695-5-8-31 x TN1


50
40
30
20
10
0
% OF PLANTS
0
1
3
5
7
9
DAMAGE SCORE (0-9)

families. F_3 plant progenies descending from resistant F_2 plants were screened using bulk seedling test. The F_3 lines were either homogeneous for resistance or segregated into resistant and susceptible types. The segregating lines showed 3:1 ratio for resistance and susceptibility. The χ^2 analysis indicated satisfactory fit to a 3:1 ratio. The data are recorded in Table 9. Out of the nine F_3 families studied, two were homogeneous for resistance and the remaining seven were heterogeneous with resistant and susceptible types.

b) CR 266-407-4 x TN1

The data on the reaction of F_3 lines of the cross are presented in Table 9. Nine F_3 families were screened using bulk seedling test. One line showed homogeneity for resistance and the remaining eight have shown segregation. Within the segregating lines, the ratio for resistant and susceptible seedlings showed a good fit to the 3:1 model.

c) RP 1015-45-114-1 x TN1

Nine F_3 lines were screened using bulk seedling test in order to confirm the F_2 results. Of these nine F_3 families, one was homogeneous for resistance and the other eight were segregating. Each segregating line showed a 3:1 ratio

Table 9 Segregation for resistance to BPH in the F_3 lines (Resistant x Susceptible crosses).

Cross No.	Cross combination	F_2 plant No.	Total no. of seedlings screened	No. of resistant seedlings	No. of susceptible seedlings	χ^2 (3:1)
1.	MTU 5295 x TN1	1	127	94	33	-
		2	101	78	23	-
		3	109	82	27	-
		4	105	105	-	-
		5	102	77	25	-
		6	98	98	-	-
		7	118	87	31	-
		8	121	90	31	-
		10	107	82	25	-
	Total no. seedlings from segregating lines		785	590	195	0.0106
2.	CR 266-407-4 x TN1	1	122	91	31	-
		2	135	100	35	-
		3	107	83	24	-
		4	120	92	28	-
		5	115	86	29	-
		6	102	77	25	-
		7	102	102	-	-
		8	111	83	28	-
		10	107	80	27	-
	Total no. of seedlings of segregating lines		919	692	227	0.0439

Table 9 (contd.)

1	2	3	4	5	6	7
3.	RP 1015-45-114-1 x TN1	1	117	88	29	-
		2	108	85	23	-
		3	104	78	26	-
		4	105	79	26	-
		5	98	98	-	-
		6	110	85	25	-
		7	116	86	30	-
		8	122	91	31	-
		11	103	77	26	-
	Total no. of seedlings of segregating lines		885	669	216	0.1661
4.	MO 6 x TN1	1	104	78	26	-
		2	101	76	25	-
		3	124	94	30	-
		4	108	80	28	-
		5	92	69	23	-
		6	112	84	28	-
		7	132	132	-	-
		8	110	83	27	-
		9	116	88	28	-
	Total no. of seedlings from segregating lines		867	652	215	0.0188

Table 9 (contd.)

1	2	3	4	5	6	7
5.	MO 7 x TN1	1	116	116	-	-
		3	111	84	27	-
		4	135	101	34	-
		5	120	89	31	-
		7	104	78	26	-
		8	118	89	29	-
		9	100	76	24	-
		11	166	125	41	-
		12	152	114	38	-
	Total no. of seedings of segregating lines		1006	756	250	0.0119
6.	M 66 B-45-1 x TN1	3	92	69	23	-
		4	118	89	29	-
		5	128	96	32	-
		7	105	79	26	-
		8	114	86	28	-
		9	147	110	37	-
		10	144	108	36	-
		11	102	77	25	-
		12	104	104	-	-
	Total no. of seedlings of segregating lines		950	714	236	0.0126

Table 9 (contd.)

1	2	3	4	5	6	7
7.	MTU 5194 x TN1	1	115	85	30	-
		3	100	100	-	-
		4	108	82	26	-
		5	123	93	30	-
		8	107	81	26	-
		9	135	103	32	-
		10	115	85	30	-
		12	132	101	31	-
		17	121	91	30	-
	Total no. of seedlings of segregating lines		956	721	235	0.0893
8.	RP 2695-5-8-31 x TN1	1	124	94	30	-
		2	131	99	32	-
		3	122	93	29	-
		5	135	102	23	-
		6	115	115	-	-
		7	130	98	32	-
		9	111	84	27	-
		10	107	81	26	-
		11	118	89	29	-
	Total no. of seedlings of segregated lines		978	740	238	0.2304

for resistance and susceptibility. The total number of seedlings screened from the eight segregating lines were 885. Out of which 669 were resistant and 216 were susceptible. χ^2 analysis revealed a good fit to the 3:1 ratio. The data are given in Table 9.

d) MO 6 x TN1

In the F_3 analysis, progenies of nine resistant F_2 plants were subjected to bulk seedling test. One progeny was homogeneous for resistance. The remaining eight F_3 progenies having 867 seedlings segregated for resistance. 652 seedlings were resistant and 215 were susceptible. There was 3:1 segregation in all the segregating F_3 lines for resistance and susceptibility. The data of F_3 analysis are given in Table 9.

e) MO 7 x TN1

Seedlings of nine F_3 progenies were screened using bulk seedling test. Of these one progeny was homogeneous for resistance and all the 116 seedlings were resistant. Seedlings evolved from the remaining eight F_2 plants segregated for resistance and susceptibility. There were a total of 1006 seedlings out of which 756 were resistant and 250 were susceptible. The ratio of resistant seedlings to

susceptible seedlings was 3:1. Progenies of all the eight segregating lines showed the 3:1 ratio for resistance and susceptibility. X^2 analysis showed that the observed ratio fits very well with the expected ratio of 3:1. The data on F_3 lines are given in Table 9.

f) M 66 B-45-1 x TN1

The F_3 seedlings were subjected to bulk seedling test. Nine F_3 progenies were tested. Only one progeny was homogeneous for resistance. There were 104 seedlings in this progeny and all of them were resistant. In the other eight F_3 lines there were a total of 950 seedlings out of which 714 were resistant and 236 were susceptible. The ratio for resistant to susceptible seedlings was 3:1. All the eight segregating lines showed 3:1 ratio for resistance and susceptibility. The data are presented in Table 9. X^2 analysis of the F_3 segregating lines showed that there was a good fit to the expected ratio of 3:1.

g) MTU 5194 x TN1

The F_3 lines were screened by bulk seedling test. Population showed one homogeneous resistant and eight heterogenous resistant lines. Within the heterogenous lines, the segregation for resistance and susceptibility was in the

ratio of 3:1. Progeny of F_3 plant No. 3 was homogeneous for resistance. There were 100 seedlings in this F_3 progeny. Progenies of the other eight F_2 plants contained resistant and susceptible seedlings in a ratio of 3:1. The segregating population consisted of a total of 956 seedlings, out of which 721 were resistant and 235 were susceptible. Statistical analysis revealed that there was a good fit to the 3:1 ratio. The data are presented in Table 9.

h) RP 2695-5-8-31 x TN1

The F_3 analysis of this cross was done by screening F_3 lines using bulk seedling test. The data are given in Table 9. There were 115 seedlings in the progeny of F_2 plant No. 6 and all of them were resistant. Progenies of the other eight F_2 plants constituted 978 seedlings out of which 740 were resistant and 238 were susceptible. The observed ratio for resistance to susceptibility was 3:1. Within the segregating lines also the observed ratio for resistance to susceptibility was the same. X^2 analysis of the segregation data revealed that there was a good fit to the 3:1 ratio.

ii) Crossing between different resistant types

From the set of eight resistant types subjected to

genetic analysis, six were selected to ascertain the genic relationship between them. They were:-

1. MTU 5295
2. CR 266-407-4
3. RP 1015-45-114-1
4. MO 6
5. MO 7
6. M 66 B-45-1

The six types were crossed among themselves in all the different combinations without reciprocals to study the allelic relationship between the types. There were fifteen combinations.

The F_1 and F_2 populations were studied for BPH resistance. F_1s were screened using all the three methods viz., bulk seedling test, tiller test and honeydew experiment. F_2 populations were screened using bulk seedling test and tiller test. The fifteen combinations made are the following:

a) MTU 5295 x CR 266-407-4
b) MTU 5295 x RP 1015-45-114-1
c) MTU 5295 x MO 6
d) MTU 5295 x MO 7

e) MTU 5295 x M 66 B-45-1

f) CR 266-407-4 x RP 1015-45-114-1

g) CR 266-407-4 x MO 6

h) CR 266-407-4 x MO 7

i) CR 266-407-4 x M 66 B-45-1

j) RP 1015-45-114-1 x MO 6

k) RP 1015-45-114-1 x MO 7

l) RP 1015-45-114-1 x M 66 B-45-1

m) MO 6 x MO 7

n) MO 6 x M 66 B-45-1

o) MO 7 x M 66 B-45-1

A. Evaluation of the F_1 generation

a) MTU 5295 x CR 266-407-4

Both the parents, MTU 5295 and CR 266-407-4 were resistant in all the screening tests. The score values for MTU 5295 were 1.7, 1.6 and 0.75 and those for CR 266-407-4 were 1.2, 1.6 and 0.70 in bulk seedling test, tiller test and honeydew experiment respectively. The score values for F_1 were 1.2, 0.8 and 0.40. The data are presented in Table 10. The parents and F_1 are shown in Figure 15(a).

b) MTU 5295 x RP 1015-45-114-1

MTU 5295 and RP 1015-45-114-1 were resistant in all

Table 10 Reaction of types and hybrids to BPH in diallel crosses between Resistant types.

Cross No.	Varieties and Hybrids	BPH Damage Score		Honey-dew excreted (cm^2)	BPH Damage rating
		Bulk seed-ling test (0-9)	Tiller test (0-9)		
1	2	3	4	5	6
1.	MTU 5295 x CR 266-407-4				
	MTU 5295	1.7	1.6	0.75	R
	CR 266-407-4	1.2	1.6	0.70	R
	F_1	1.2	0.8	0.40	R
2.	MTU 5295 x RP 1015-45-114-1				
	MTU 5295	1.7	1.6	0.75	R
	RP 1015-45-114-1	1.8	1.3	0.90	R
	F_1	1.0	1.7	0.45	R
3.	MTU 5295 x MO 6				
	MTU 5295	1.7	1.6	0.75	R
	MO 6	2.0	2.0	0.75	R
	F_1	2.0	1.9	0.35	R
4.	MTU 5295 x MO 7				
	MTU 5295	1.7	1.6	0.75	R
	MO 7	2.0	1.6	0.75	R
	F_1	2.0	0.9	0.90	R

Table 10 (contd.)

1	2	3	4	5	6
5.	MTU 5295 x M 66 B-45-1				
	MTU 5295	1.7	1.6	0.75	R
	M 66 B-45-1	1.8	1.2	1.00	R
	F_1	1.5	1.0	0.75	R
6.	CR 266-407-4 x RP 1015-45-114-1				
	CR 266-407-4	1.2	1.6	0.70	R
	RP 1015-45-114-1	1.8	2.3	0.90	R
	F_1	1.5	1.6	1.00	R
7.	CR 266-407-4 x MO 6				
	CR 266-407-4	1.2	1.6	0.70	R
	MO 6	2.0	2.0	0.75	R
	F_1	1.5	1.5	0.95	R
8.	CR 266-407-4 x MO 7				
	CR 266-407-4	1.2	1.6	0.70	R
	MO 7	2.0	1.6	0.75	R
	F_1	1.5	1.5	0.75	R
9.	CR 266-407-4 x M 66 B-45-1				
	CR 266-407-4	1.2	1.6	0.70	R
	M 66 B-45-1	1.8	1.2	1.00	R
	F_1	1.5	1.0	0.85	R

Table 10 (contd.)

1	2	3	4	5	6
10.	RP 1015-45-114-1 x MO 6				
	RP 1015-45-114-1	1.8	2.3	0.90	R
	MO 6	2.0	2.0	0.75	R
	F_1	2.0	2.0	0.75	R
11.	RP 1015-45-114-1 x MO 7				
	RP 1015-45-114-1	1.8	2.3	0.90	R
	MO 7	2.0	1.6	0.75	R
	F_1	2.0	2.1	0.75	R
12.	RP 1015-45-114-1 x M 66 B-45-1				
	RP 1015-45-114-1	1.8	2.3	0.90	R
	M 66 B-45-1	1.8	1.2	1.00	R
	F_1	1.5	2.0	0.75	R
13.	MO 6 x MO 7				
	MO 6	2.0	2.0	0.75	R
	MO 7	2.0	1.6	0.75	R
	F_1	2.0	1.5	0.90	R

Table 10 (contd.)

1	2	3	4	5	6
14.	MO 6 x M 66 B-45-1				
	MO 6	2.0	2.0	0.75	R
	M 66 B-45-1	1.8	1.2	1.00	R
	F_1	1.5	2.0	0.95	R
15.	MO 7 x M 66 B-45-1				
	MO 7	2.0	1.6	0.75	R
	M 66 B-45-1	1.8	1.2	1.00	R
	F_1	1.5	1.5	0.80	R

R - Resistant

Figure 15

Varieties and F_1 in Resistant x Resistant Crosses

a. MTU 5295 x CR 266-407-4

b. MTU 5295 x RP 1015-45-114-1

a. b.

FIGURE. 15. (CONTD:)

c.

d.

FIGURE. 15. (CONTD:)

e.

f.

FIGURE · 15. (CONTD;)

the three screening tests. Data are given in Table 10. The F_1 seedlings were also resistant. The parents and F_1 are shown in Figure 15(b). The score values for MTU 5295 were 1.7, 1.6 and 0.75 respectively for bulk seedling test, tiller test and honeydew experiment and the values for RP 1015-45-114-1 were 1.8, 1.3 and 0.9. The F_1s scored 1.0, 1.7 and 0.45 for these three tests. The parents along with F_1 are shown in Figure 15(b).

c) MTU 5295 x MO 6

The parents MTU 5295 and MO 6 were screened using the three screening tests and in all the tests, they were resistant. The F_1s also showed resistance and resembled the parents in resistance. The data of screening tests of parents and F_1 are given in Table 10. The F_1 and parents can be seen in Figure 15(c).

d) MTU 5295 x MO 7

Like the parents MTU 5295 and MO 7, the F_1s were resistant. The parents and F_1s were screened using bulk seedling test, tiller test and honeydew experiment. The results of the three screening tests are given in Table 10. The parents and F_1 are shown in Figure 15(d). The score values for F_1 were 2.0, 0.9, and 0.9 respectively in bulk

Figure 15 (contd.)

c. MTU 5295 x MO 6

d. MIU 5295 x MO 7

seedling test, tiller test and honeydew experiment.

e) MTU 5295 x M 66 B-45-1

The parents MTU 5295 and M 66 B-45-1 were resistant in all the three screening tests. The score values for MTU 5295 were 1.7, 1.6 and 0.75 for bulk seedling test, tiller test and honeydew experiment respectively and the values for M 66 B-45-1 were 1.8, 1.2 and 1.0. These values for F_1s were 1.5, 1.0 and 0.75. Like the parents, the F_1s also showed resistance. The data are given in Table 10. Figure 15(e) represents the parents and the F_1.

f) CR 266-407-4 x RP 1015-45-114-1

The F_1 plants resembled their parents in resistance. The data of the screening tests are given in Table 10. Figure 15(f) shows the parents and the F_1. The score values of CR 266-407-4 were 1.2, 1.6 and 0.70 respectively for bulk seedling test, tiller test and honeydew experiment. The score values for RP 1015-45-114-1 were 1.8, 2.3 and 0.90 and these for F_1 were 1.5, 1.6 and 1.00 respectively.

g) CR 266-407-4 x MO 6

Like the parents, the F_1 population also showed resistance in all the three screening tests. The results of the

Figure 15 (contd.)

c. MTU 5295 x M 66 B-45-1

f. CR 266-407-4 x RP 1015-45-114-1

three screening tests with regard to the parents and F_1s are given in Table 10. Figure 15(g) shows the parents and the F_1. The score values of MO 6 were 2.0, 2.0 and 0.75 respectively for bulk seedling test, tiller test and honeydew experiment. The score values for the F_1 were 1.5, 1.5 and 0.95.

h) CR 266-407-4 x MO 7

In all the three screening tests, both the parents and the F_1s showed resistance. The F_1s resembled the parents in resistance. The data of three screening tests are shown in Table 10. The parents and the F_1 are shown in Figure 15(h). Score values of CR 266-407-4 were 1.2, 1.6 and 0.7 respectively for bulk seedling test, tiller test and honeydew experiment while these for MO 7 were 2.0, 1.6 and 0.75 and for F_1 were 1.5, 1.5 and 0.75.

i) CR 266-407-4 x M 66 B-45-1

Both the parents and F_1s were subjected to bulk seedling test, tiller test and honeydew experiment. In all the three tests both the parents and F_1s were resistant. Score values for M 66 B-45-1 were 1.8, 1.2, 1.0 respectively for bulk seedling test, tiller test and honeydew experiment and these for F_1 were 1.5, 1.0 and 0.85. The data are given

Figure 15 (contd.)

g. CR 266-407-4 x MO 6

h. CR 266-407-4 x MO 7

in Table 10. In Figure 15(i) the parents and F_1 are presented.

j) RP 1015-45-114-1 x MO 6

The parent RP 1015-45-114-1 scored 1.8, 2.3 and 0.90 respectively for bulk seedling test, tiller test and honeydew experiment. The values for MO 6 were 2.0, 2.0 and 0.75 and those for F_1 were exactly the same in all the three tests. The data of the three screening tests are given in Table 10 and the parents and the F_1 are shown in Figure 15(j). Like both the parents, the F_1 also showed high resistance.

k) RP 1015-45-114-1 x MO 7

Like the parents, the F_1s were also resistant. MO 7 showed the score values as 2.0, 1.6 and 0.75 whereas the F_1 gave the score values as 2.0, 2.1 and 0.75 respectively for bulk seedling test, tiller test and honeydew experiment. The score values of F_1 and the parents are given in Table 10. The parents and F_1 are shown in Figure 15(k).

l) RP 1015-45-114-1 x M 66 B-45-1

The F_1s resembled the parents in resistance with the score values 1.5, 2.0 and 0.75 respectively for bulk screening test, tiller test and honeydew experiment. The data of the three screening tests for the parents and F_1 are given

Figure 15 (contd.)

i. CR 266-407-4 x M 66 B-45-1

j. RP 1015-45-114-1 x MO 6

i.

j.

FIGURE. 15. (CONTD:)

Figure 15 (contd.)

k. RP 1015-45-114-1 x MO 7

l. RP 1015-45-114-1 x M 66 B-45-1

k.

l.

FIGURE. 15. (CONTD:)

Figure 15 (contd.)

m. MO 6 x MO 7

n. MO 6 x M 66 B-45-1

in Table 10. Figure 15(1) shows the parents and the F_1. The score values for RP 1015-45-114-1 were 1.8, 2.3 and 0.9 and that for M 66 B-45-1 were 1.8, 1.2 and 1.0.

m) MO 6 x MO 7

The F_1 seedlings of the cross MO 6 x MO 7 were resistant. They have scored 2.0, 1.5 and 0.90 in bulk seedling test, tiller test and honeydew experiment. The score values of the parents were also two or less in all the screening tests. The F_1s resembled the parents in resistance. The score values of both the parents and F_1s are presented in Table 10 and parents and F_1 are shown in Figure 15(m).

n) MO 6 x M 66 B-45-1

The F_1 seedlings were resistant with score values of 1.5, 2.0 and 0.95 in bulk seedling test, tiller test and honeydew experiment respectively. In both the parents, the score values were two or less in all the tests. The hybrids resembled both the parents in resistance. The data on damage scores of parents and F_1 are given in Table 10. MO 6, M 66 B-45-1 and the hybrid are shown in Figure 15(n).

o) MO 7 x M 66 B-45-1

Both the parents were resistant with score values of

m. n.

FIGURE. 15. (CONTD:)

2.0, 1.6 and 0.75 for MO 7 and 1.8, 1.2 and 1.0 for M 66 B-45-1 in bulk seedling test, tiller test and honeydew experiment respectively. Like the parents, the F_1s also had low scores of 1.5, 1.5 and 0.80. Hybrids therefore were resistant to BPH similar to the parents. The score values are given in Table 10. The parents (MO 6, M 66 B-45-1) and the hybrid are shown in Figure 15(o).

B. Evaluation of F_2 progenies

a) MTU 5295 x CR 266-407-4

Screening of the F_2 progeny revealed that all the plants were resistant like the F_1s and the parents. The F_2 progeny did not show segregation for resistance. A total of 205 seedlings were screened and all of them were resistant. Data of bulk seedling test and tiller test are recorded in Table 11.

b) MTU 5295 x RP 1015-45-114-1

Two hundred and fortyone F_2 seedlings were screened. In bulk seedling test and tiller test all the F_2 seedlings were found to be resistant, like the parents and the F_1. The data on F_2 screening are presented in Table 11.

c) MTU 5295 x MO 6

In the F_2 population, none of the seedlings showed

O.

FIGURE. 15. (CONTD:)

Table 11. Segregation for resistance to BPH in the F_2 populations of diallel crosses between Resistant types.

Cross No.	Cross combinations	No. of seedlings screened	No. of Resistant seedlings		No. of susceptible seedlings	Percentage of susceptible seedlings
			Bulk seedling test	Tiller test*		
1	2	3	4	5	6	7
1.	MTU 5295 x CR 266-407-4	205	205	205	0	0
2.	" x RP 1015-45-114-1	241	241	241	0	0
3.	MTU 5295 x MO 6	208	208	208	0	0
4.	" x MO 7	227	227	227	0	0
5.	" x M 66 B-45-1	231	231	231	0	0
6.	CR 266-407-4 x RP 1015-45-114-1	261	261	261	0	0
7.	CR 266-407-4 x MO 6	228	228	228	0	0
8.	" x MO 7	215	215	215	0	0
9.	" x M 66 B-45-1	221	221	221	0	0

Table 11 (contd.)

1	2	3	4	5	6	7
10.	RP 1015-45-114-1 x MO 6	207	207	207	0	0
11.	RP 1015-45-114-1 x MO 7	212	212	212	0	0
12.	" x M 66 B-45-1	236	236	236	0	0
13.	MO 6 x MO 7	251	251	251	0	0
14.	MO 6 x M 66 B-45-1	248	248	248	0	0
15.	MO 7 x M 66 B-45-1	236	236	236	0	0

* Computed value

the damage score of above 3. All the 208 F_2 seedlings were thus resistant like the parents and the F_1. In both the screening tests, segregation for resistance was totally absent. The data on screening F_2 seedlings are given in Table 11.

d) MTU 5295 x MO 7

In both the screening tests, all the 227 F_2 seedlings showed resistance like the parents MTU 5295 and MO 7 and the F_1. The data on both the screening tests are given in Table 11 No segregation for resistance was noticed among the seedlings screened.

e) MTU 5295 x M 66 B-45-1

The screening of 231 F_2 seedlings revealed that like the F_1s and parents, the F_2s were also totally resistant. In both the screening tests the F_2 showed resistance. The data on screening are given in Table 11.

f) CR 266-407-4 x RP 1015-45-114-1

All the 261 F_2 seedlings were resistant in both the screening tests. They resembled the parents and the F_1 in resistance. The data of screening are given in Table 11.

g) CR 266-407-4 x MO 6

Like the parents (CR 266-407-4 and MO 6) and the F_1, the 228 F_2 seedlings showed resistance in both the tests indicating the absence of segregation for resistance. The data of both the screening tests are given in Table 11.

h) CR 266-407-4 x MO 7

In the F_2 population, none of the 215 seedlings showed susceptibility to BPH. The F_2 population was thus homogeneous for resistance. They resembled the parents, CR 266-407-4 and MO 7 and the F_1s in resistance. The data regarding the screening tests are shown in Table 11.

i) CR 266-407-4 x M 66 B-45-1

In the F_2 population there were 221 seedlings. They were subjected to bulk seedling test and tiller test. All the seedlings were resistant. The data of both the screening tests are presented in Table 11.

j) RP 1015-45-114-1 x MO 6

The parents RP 1015-45-114-1 and MO 6 were resistant. Like the parents and the F_1s, all the 207 F_2 seedlings were resistant. They were screened using bulk seedling test and

tiller test. In both the tests, none of the F_2 seedlings showed susceptibility. The data of bulk screening test and tiller test are presented in Table 11.

k) RP 1015-45-114-1 x MO 7

The F_2 population were subjected to bulk seedling test and tiller test for screening against BPH. There were 212 seedlings. The F_2 progeny did not show segregation for resistance. They resembled the F_1s and the parents in respect of resistance. The data of screening of F_2 seedlings are given in Table 11.

l) RP 1015-45-114-1 x M 66 B-45-1

Two hundred and thirtysix F_2 seedlings were screened using bulk seedling test and tiller test. Like the parents RP 1015-45-114-1 and M 66 B-45-1, and the F_1s, all the F_2 seedlings were resistant. The data of screening F_2 seedlings are given in Table 11.

m) MO 6 x MO 7

F_2 analysis revealed that all the 251 seedlings subjected to bulk seedling test and tiller test were resistant. They resembled the parents and the F_1s in resistance. The data on F_2 seedlings are given in Table 11.

n) MO 6 x M 66 B-45-1

F_2 analysis revealed that all the 248 seedlings were resistant. They were screened using bulk seedling test and tiller test. There was no segregation for BPH resistance. The data of screening F_2 seedlings are given in Table 11.

o) MO 7 x M 66 B-45-1

The parents (MO 7 and M 66 B-45-1) and the F_1 were resistant. The 236 F_2 seedlings also showed resistance. They were screened using bulk seedling test and tiller test. All the seedlings showed resistance to BPH indicative of homogeneity. The data of both the screening tests are shown in Table 11.

DISCUSSION

DISCUSSION

The Brown planthopper, Nilaparvata lugens (Stal) is considered to be the number one insect pest of rice in Asia today. Although timely application of insecticides provides effective control, large scale chemical control is difficult and expensive. Moreover, repeated sprayings upset the natural balance between the insect and its natural enemies. The logical and economic approach for effective control of BPH would therefore be the use of host plant resistance. In recent years, resistant varieties have received better attention because of the increasing awareness of the short comings of chemical pesticides and the effectiveness of genetic resistance.

The first step in a resistance breeding programme is the screening of the available germplasm for resistance to the pest. This resistance when compatible with other desirable plant characters can be incorporated into new varieties. Large scale cultivation of resistant varieties over a long period of time is likely to lead to the build up of new biotypes to which the varieties succumb. To cope with highly dynamic pests like the brown planthopper, which can develop biotypes to overcome varietal resistance, it is imperative that varieties with diverse genetic background

be developed. Sequential release of resistant varieties with resistance to newly emerging biotypes is also essential. For this purpose it is necessary to identify as many genes for resistance as possible. Incorporating diverse genes into specific genotypes would ensure stability of resistance against the different biotypes. The study of inheritance of BPH resistance makes possible the identification of resistant donor varieties and the genes governing resistance. A thorough and clear understanding of the mode of inheritance of resistance is also essential in breeding for resistance.

The present study was undertaken to screen rice varieties against BPH to identify resistant ones and to study the mode of inheritance of BPH resistance.

I. Identification of the sources of resistance:

Sources have to be identified for incorporating resistance in the breeding programmes. Several sources have been identified by Gunavardhana et al. (1975) and Kudagamage (1976) in Sri Lanka; Seshu and Kauffman (1980); Mugiano et al. (1984), Heinrichs et al. (1985) and IRRI (1978) in Philippines; Mochida et al. (1976) in Indonesia; Kalode and Krishna (1979), Krishna et al. (1980), Natarajan

and Chandy (1980), Reddy and Kalode (1981), Veluswamy and Chelliah (1984), Rao and Padhi (1986), Thomas (1976), Nair et al. (1978) and Das et al. (1984) in India; Lee et al. (1984) in China; Choi (1980) in Korea and Kabir and Alum (1981) and Dong et al. (1985) in Solomon Islands.

Screening for resistance is being done by three screening tests viz., bulk seedling test at the seedling stage and tiller test and honeydew experiment at the tillering stage. The field screening method allows the grading of the varieties as resistant, moderately resistant, moderately susceptible and susceptible. Since the natural field population is usually low and uneven, screening is generally done in the greenhouse where a better differentiation of the varieties is possible. The main purpose of screening is to facilitate the quick rejection of the BPH susceptible lines. The test varieties are tested in the greenhouse for consistency of basic insect-host plant interrelationships by determining the preference of the insects for the cultivars, or the antibiosis effect of the cultivars on the insects or both. Varietal screening at the seedling stage in the greenhouse is done by employing the basic screening procedures standardised by Choi (1979). These basic techniques were introduced in Japan by Kaneda and

Kisimoto (1979) in India by Kalode et al. (1975) and in Thailand by Pongprasert and Weerapat (1979).

Two characteristics that emerge from seedling screening for BPH resistance are the frequent inconsistency of the results and the absence of gradation of symptoms of damage leading to plant death. Seedling susceptibility or resistance does not necessarily continue until the later stages of plant growth. Therefore another method of screening at the tillering stage has been described by Pathak and Khush (1979) in Philippines; Fernando et al. (1979) in Sri Lanka and Thomas (1977) in India.

Honeydew deposition by planthoppers has been used as a measure of the insects food intake and resistance of the host plant to insect attack (Sogawa and Pathak, 1970; Karim, 1975 and Kalode et al., 1975). They reported that insect feeding on resistant cultivars was restricted. Lower survival rates and lower population build up were thus associated with less feeding on resistant varieties. It has been reported that the amount of honeydew excreted is positively correlated with the amount of food ingested. The quantity of honeydew excreted can therefore be used as a criterion for the quantitative assessment of insect feeding (IRRI, 1968). An estimate of honeydew excreted by BPH on resistant and susceptible

varieties was reported by Lee and Park (1976). They have reported that BPH excreted less honeydew when feeding on resistant plants than on susceptible varieties. Pathak and Khush (1979) had described the method of honeydew experiment to find out the differences in amount of honeydew excreted to determine the amount of feeding by adult planthopper.

One hundred and nine rice varieties and types were collected. Out of these, eight varieties were from Sri Lanka, 21 from Philippines, 75 from India, three from Indonesia and two from Taiwan. To identify sources of resistance, these varieties were screened using the bulk seedling test introduced by Choi (1979). Based on this, 41 types were found to be resistant with a score in between 1 and 3 in the 0-9 scale. Twentytwo types have shown moderate resistance with score in between 3 and 5. Thirteen varieties have shown the score in between 5 and 7 with moderate susceptibility. Thirtythree varieties were highly susceptible to BPH with a score above 7. Similar results were reported by Veluswamy and Chelliah (1984). They have evaluated 465 rice accessions in the greenhouse by the seedling bulk screening method and identified ASD 11, IET 5741, IET 6315, T7 and V.P. Samba as resistant. In Indonesia, Mochida et al. (1976) evaluated some lines and recorded that rice varieties IR 26, IR 28,

IR 30, Ptb 19, Ptb 33 and ARC 6650 were resistant. Kalode and Krishna (1979) evaluated 914 cultivars from North east India and found that 61 were resistant and about 15 varieties showed a high level of resistance. Thomas (1976) screened 11 varieties and found that Ptb 19, Ptb 33 and ARC 6650 were resistant. Krishna et al. (1980) have identified 66 tall traditional varieties of rice mostly from India but some from Vietnam and Sri Lanka known to be resistant. Rao and Padhi (1986) screened 45 entries out of which seven were resistant to BPH. Lee and Ye-Yuantian (1984) in China screened 313 varieties and found that 37 were resistant. Kabir and Alum (1981) in Bengladesh have reported that ten out of the 450 varieties screened were highly resistant and 27 were resistant. Dong and Taro (1985) studied the resistance of the cultivar BG 3795 (BG 96-3/Ptb 33) in 1980 IRBPHN in Solomon Islands and found that it was highly resistant. This line is believed to possess the Ptb 33 resistant gene. Gunavardhana et al. (1975) studied the resistance of 1000 varieties in Sri Lanka and reported that four varieties were highly resistant. Kudagamage (1976) also screened 500 varieties in Sri Lanka and recorded that Ptb 33, ARC 6650, Sudurusamba, MR 1523 and SuduHeenati were highly resistant. Heinrichs et al. (1985) evaluated IR varieties in the greenhouse in Philippines and stated that recently recommended

IR varieties are resistant to biotypes 1, 2 and 3 of BPH. Natarajan and Chandy (1980) tested 204 rice cultivars in India and reported that none was immune to attack, but some of these showed a certain degree of resistance.

Fortyone resistant types obtained from the bulk seedling test were subjected to the tiller test for further screening. Of these, 31 have shown resistance to BPH with scores 0-3 in the 0-9 scale. Nine entries have shown moderate resistance with scores in between 3 and 5 and one variety showed moderate susceptibility with a score of 6.3. This finding agrees with the report of Veluswamy and Chelliah (1984). They have evaluated 465 accessions by bulk seedling test of which five were identified as resistant. Their resistance was further confirmed by the tiller test. The resistant accessions were ASD 11, IET 5741, IET 6315, T7 and V.P. Samba. Thomas (1977) screened fiftysix varieties by tiller test of which one variety (Ptb 33) was found to be resistant and Cul. M11-57-5-1 was moderately resistant.

An estimate of honeydew excreted by BPH on 31 resistant varieties obtained from tiller test was done. Results revealed that the relative amount of honeydew excreted by female adults of BPH was much less after feeding on resistant varieties than after feeding on the susceptible variety

TN1. Damage rating was done based on the amount of honeydew excreted by BPH. Of the 31 resistant types tested, 30 have shown resistance to BPH (with 0-3 cm^2 of honeydew) and one has shown moderate resistance (with 3.05 cm^2 of honeydew) as compared to the susceptible check variety TN1 (with honeydew 7.50 cm^2). The difference observed in honeydew excretion has been used as a reliable index of the degree of host-plant resistance.

A similar result was reported by Sogawa and Pathak (1970). They have reported that the insects did not exhibit any difference in their alighting behaviour in different varieties but they did not stay on resistant plants for sustained feeding. The latter response was so strong for BPH caged on the resistant variety 'Mudgo' that the insects starved to death rather than feeding on plants. Melahuyoe and Heinrichs (1981) reported, honeydew excretion, feeding activity and insect weight gain as criteria in determining levels of varietal resistance in the Philippines. Weight of honeydew excreted on the susceptible variety was 2.5 times to that excreted on the resistant variety. Based on IRRI report (1978), insects caged on susceptible varieties gained significantly more weight than those caged on resistant varieties. They also excreted honeydew copiously on susceptible varieties but scantly and intermittently on resistant

varieties. The amount of honeydew excreted generally depended on the amount of food ingested. Kalode et al. (1975) from their honeydew experiment reported that insect feeding on resistant cultivars was restricted. Insects on susceptible varieties TN1 and Leb Mue Nahng excreted heavily. The data also show a possible correlation between insect survival, population build up and honeydew excretion. Lower survival rates and lower population build up were thus associated with less feeding on resistant varieties. The differences observed in the honeydew excretion might therefore be used as an indirect index of the degree of resistance. Utilizing the ninhydrin method, Lee and Park (1976) investigated the relative amount of honeydew excreted by BPH fed on some selected Korean lines. It was also apparent from their studies that BPH excreted less honeydew when feeding on resistant plants than on susceptible varieties. In their study, the range for the amount of honeydew in resistant varieties was 0.09 to 1.00 cm^2 whereas the amount of honeydew excreted on the susceptible variety TN1 was 5.3 cm^2.

According to Pathak and Khush (1979), 26,000 rice varieties have been screened at the International Rice Research Institute, Philippines. About 500 varieties that had damage grades of 1 to 5 were selected to be retested for resistance

to the three biotypes. Subsequently, 268 selections were classified as resistant to biotype 1, 110 to biotype 2, and 95 to biotype 3. Varieties resistant to one biotype were not necessarily resistant to the other two. About 50 varieties or selections were identified as resistant to all the three biotypes. No variety susceptible to biotype 1 was resistant to biotype 2 or 3. Several breeding lines from IRRI and India are resistant or moderately resistant to the three biotypes. Heinrichs et al. (1985) evaluated IR varieties in greenhouse, screenhouse and fields in Philippines against BPH. According to them, recently developed IR varieties were resistant to biotypes 1, 2 and 3.

Mudgo, MTU 15, ASD 7 and Ptb 18 were reported to be resistant to BPH in the Philippines (Athwal et al., 1971). However in the present study, Mudgo and MTU 15 were found to be moderately resistant with score values of 4.1 and 3.2 respectively. ASD 7 was highly susceptible with score of 7.2 and Ptb 18 was moderately susceptible with score value of 6.5.

Vellailangayan, RatuHeenati and Babawee were found to be moderately resistant in the present study with score values of 3.2, 4.5 and 4.6 respectively. Lekshminarayana and Khush (1977) have reported that these varieties were

resistant in the Philippines.

Varieties like Mudukiriyal, Lekhamsamba, Sadu-Hondarawala and Sinnasivappu were reported to be resistant in the Philippines (Sidhu and Khush, 1978). In the present investigation, Mudukiriyal was found to be moderately susceptible with score value of 6.9 and SuduHondarawala was found to be moderately resistant with score value of 3.4. "Lekhamsamba" and "Sinnasivappu" on the other hand were found to be resistant here also with score values of 2.6 and 2.9 respectively.

According to Pathak and Khush (1979), IR 38 and IR 40 were resistant in the Philippines. In the present investigation also IR 40 was resistant with score value of 2.4 but IR 38 was found to be highly susceptible with score value of 7.3.

The variety MO 7 found to be resistant in the present study has been derived from the cross between IR 1539 and Triveni. IR 1539 is reported to be resistant in the Philippines (Pathak and Khush, 1979; and Seshu and Kauffman, 1980). IR 1539 has been reported to be derived from the cross IR 24/Mudgo/IR 8 and this variety has inherited its resistance from Mudgo. In the present study, Mudgo was only

moderately resistant with a damage score of 4.1.

Another type found resistant in the present study was CR 266-407-4 evolved from the cross CR 94-1512-6 x Ratna. Based on the reports of IRRI (1982) and Pathak and Khush (1979), CR 94-1512-6 was derived from the cross between Ptb 18 and Ptb 21. Ptb 18 was found to be resistant at IRRI and CR 94-1512-6 inherited its resistance from Ptb 18. In the present study, Ptb 18 was found to be moderately susceptible with a damage score of 6.5.

The type M 66 B-45-1 evolved from the cross between B 4598-PN-132-9-3 and IR 2071-588-56 was found to be resistant in the present investigation. IR 2071 is the derivative of the cross IR 8/Tadukan/TKM 6/TN1/IR 24/O.nivara/4/ CR 94-13 and it inherited its resistance from CR 94-13 which is resistant in the Philippines (Khush, 1977; Pathak and Khush, 1979). These differences in BPH resistance recorded in the present investigation and reported in the Philippines may be due to the prevalence of a different biotype of BPH in these regions.

Breeding for resistance has been complicated by the existence of BPH populations that differ in their ability to feed on rice varieties. The term biotype has been used for these populations. According to IRRI (1982) there were

distinct differences in the reactions of the different rice varieties to BPH populations in the various countries. No variety was resistant at all sites. Based on the results of the work done at IRRI, at least six different BPH populations were evident. Biotype 1 that exists in the Philippines is similar to the biotype present in China, Japan, Korea, Malaysia, Taiwan and Thailand where varieties with Bph1, bph2, Bph3 and bph4 are resistant or moderately resistant. Biotype 2 which exists in Philippines, Vietnam and Solomon Islands where varieties with bph2, Bph3 and bph4 are resistant. Biotype 3 present in the Philippines and Taiwan where varieties with Bph1, Bph3 and bph4 are resistant. Another type of BPH population which exists in Bangladesh and Hyderabad (India) where varieties with Bph3 and bph4 are resistant. Yet another type is present in Coimbatore (India) where varieties with bph4 are resistant but varieties with Bph3, Bph1 and bph2 are susceptible. The sixth type is present in Pantnagar (India) where varieties with Bph1, bph2, Bph3 and bph4 are susceptible. Fernando et al. (1979) reported that BPH found in Sri Lanka differs greatly from the biotypes found in the Philippines. The varieties with Bph1 and bph2 found to be resistant to the Philippine biotypes were highly susceptible to the Sri Lankan biotype. Pathak and Khush (1979) also stated that several

biotypes of BPH existed and the biotypes in India and Sri Lanka are apparently different. They have reported that varieties with Bph1 are resistant to IRRI biotype 1 and 3 and varieties with bph2 are resistant to IRRI biotypes 1 and 2. Varieties with Bph3 and bph4 are resistant to all the three IRRI biotypes. Seshu and Kauffman (1980) reported from the results of international screening programmes that several breeding lines derived from Ptb 33 were promising in all test sites of Asia and Solomon Islands. Genes conveying resistance to BPH in Ptb 33 in South Asia appear to be different from those in the rest of Asia as is evident from the differential reactions of semidwarf selections from that variety. Saxena and Barrion (1983) reported that biotype 1 can survive on rice varieties which do not carry genes for resistance, while biotype 2 survives on resistant varieties carrying Bph1 gene and biotype 3 survives on varieties carrying gene bph2. None of these biotypes survives on varieties carrying genes Bph3 or bph4. Several varieties resistant in Philippines are susceptible in India and Sri Lanka as South Asian biotypes are more virulent than South East Asian biotypes. Veluswamy et al. (1984) noticed differential varietal reactions to BPH in the Philippines and S.India and indicated that the BPH population in Tamil Nadu and Pondichery are different from the South East Asian population.

II. Study of genetic basis of resistance

An understanding of the genetic basis of BPH resistance in rice can be of considerable plant breeding value. Here resistant varieties were crossed with the susceptible variety TN1, to study the mode of inheritance of resistance. Then resistant varieties were crossed between themselves to locate divergent genetic basis for resistance and to incorporate different genes into a single variety for building a strong genetic base conferring higher stability for resistance.

A set of crosses were undertaken to study the genetic control of BPH resistance with eight types selected from among the 30 types proved to be resistant in all the three screening tests. Each of the resistant types was crossed with the standard susceptible variety TN1. The F_1, F_2 and F_3 populations of the eight crosses were tested to determine the mode of inheritance of resistance to the BPH. In all the eight crosses, the F_1s were found to be resistant, thereby indicating the dominant nature of resistance in all the resistant varieties. The F_2 populations of these crosses segregated in the ratio of 3 resistant: 1 susceptible indicating the monogenic dominant condition of resistance in these eight types. The conclusion about the monogenic

control of resistance in these varieties was confirmed by the screening results of F_3 families. The F_3 families from F_2 resistant plants were either homogenous for resistance or heterogenous segregating into 3 resistant: 1 susceptible. It is assumed that the F_2 ratio was 1 resistant: 2 segregating: 1 susceptible because for every nine F_3 lines there was at least one homogenous resistant line and several heterogenous lines. Thus resistance in each of these eight resistant types was governed by a single dominant gene.

Previous reports support this finding. Athwal et al. (1971) reported that dominant alleles at Bph1 locus govern resistance in three varieties, Mudgo, CO 22 and MTU 15. In 1972, one more variety was investigated, MGL 2 with Bph1 gene for resistance. Martinez and Khush (1974) reported that IR 747 B2-6 has a dominant gene for resistance that is allelic to Bph1. Ikeda and Kaneda (1981) reported that the resistance of Andaragahawee to be monogenically controlled by Bph1. Lin (1980) reported that the resistance of variety Taichungsenyu 223 is controlled by a single dominant gene Bph1 and that of IR 135-39-11-1 by a single dominant gene Bph3, Lekshminarayana and Khush (1977) have reported that a single dominant gene Bph3 conveys resistance in RatuHeenati. They have identified nine varieties carrying a single dominant gene Bph1 for resistance viz. Balamawee, CO 10,

Heenukkulama, MTU 9, Sinnakayam, SLO 12, Sudhubalawee, Sudurwee 305 and Tibiriwewa. Sidhu and Khush (1978) reported that a single dominant gene Bph3 governs resistance in seven varieties viz. Ptb 19, Gangala 7733, Gangala 15207, Horanamawee, Kuruhondarawala, Mudukiriyal and Muthumanikom. Veluswamy and Chelliah (1985) reported that a single dominant gene governs resistance in ASD 11, IET 5741, IET 6215, T7 and V.P. Samba. Ikeda and Kaneda (1986) reported that Balamawee, Kaharamana and Pokali had an unknown dominant gene for resistance to BPH. Cheng and Chang (1979) reported that varieties MTU 9, Sudurvi 306 and Murunga 137 possess single dominant gene for resistance to BPH. The reports of Rao et al. (1987) on nine genes and Veluswamy and Saxena (1989) on 6 genes confiring resistance to BPH, however were not very conclusive.

For crosses between resistant varieties, six resistant varieties with single dominant gene for resistance were selected. There were 15 crosses in all possible combinations. In all the crosses, the F_1s were found to be resistant. The F_2 populations of all the crosses were evaluated for BPH resistance and all of them were homogenous for resistance. This shows that the same dominant gene is responsible for resistance in all the six resistant types. Such isoallelic dominant genes were reported in six resistant varieties by Lakshminarayana and Khush (1977). These varieties possess Bph1 gene for resistance. Sidhu and Khush

(1978) analysed 10 cultivars having dominant genes for resistance and reported that the same dominant gene Bph3 conveys resistance in these varieties.

MO 7 is a resistant variety derived from IR 1539 x Triveni. Resistance in IR 1539 has been reported to be governed by Bph1 gene (Pathak and Khush, 1979; Seshu and Kauffman, 1980). This variety in turn was derived from the cross IR 24//Mudgo/IR 8. 'Mudgo' also holds the dominant gene Bph1 for resistance (Athwal et al., 1971). In the present study, 'Mudgo' was found to be only moderately resistant with a damage score of 4.1. Similarly the variety 'RatuHeenati' with Bph3 gene was also found to be only moderately resistant with a damage score of 4.5. Bph1 and Bph3 are the only identified dominant genes. According to Saxena and Barrion (1983), several varieties resistant in the Philippines are susceptible in India and Sri Lanka as the South Asian biotypes are more virulent than the South east Asian biotypes. In the present investigation, MO 7 was found to be resistant with a dominant gene for resistance. Hence, it is concluded that the dominant resistant gene present in MO 7 and the other five resistant varieties subjected to genetic analysis is neither Bph1 nor Bph3. The present study thus does not reveal scope for broadening

the genetic base for resistance to BPH by combining more than one resistance gene.

The F_3 generation of the first set of eight crosses and the F_2 generation of the second set of 15 crosses could be advanced to identify new types combining BPH resistance with desirable productivity characters. Resistance to the local biotype of BPH can be incorporated into the locally acceptable but susceptible high yielding varieties through recombination utilizing the resistant types identified in the present study. From among the 30 types identified as resistant, only eight were subjected to genetic analysis. The remaining types can also be analysed to identify new sources of resistance.

The present study has thus made available several types resistant to the local biotype of BPH and also enabled the location of a new dominant gene conferring resistance to this biotype. These results and the materials made available can form the basis for a more effective breeding approach for BPH resistance in this region.

SUMMARY

SUMMARY

The major objectives of the present study were to screen rice varieties against BPH for identifying types resistant to the local biotype and genetic studies to understand the mode of inheritance of resistance.

One hundred and nine varieties including local types were collected from the International Rice Research Institute, Philippines, Directorate of Rice Research, Hyderabad, Central Rice Research Institute, Cuttack, Regional Agricultural Research Station, Pattambi and Rice Research Station, Moncompu. These types were screened in the green house using three screening tests at the two stages of growth viz., bulk seedling test at the seedling stage and tiller test and honeydew experiment at the tillering stage.

In the bulk seedling test, out of the 109 types, 41 were resistant, 22 were moderately resistant, 13 were moderately susceptible and 33 were highly susceptible. Fortyone types which were found resistant under this test were subjected to tiller test, of which 31 were resistant, 9 moderately resistant and one moderately susceptible. These 31 resistant types were subjected to the honeydew experiment of which 30 were resistant and one was moderately resistant.

Eight types of diverse origin which have shown a high level of resistance in the three screening tests were subjected to genetic analysis to study the genetic basis of resistance. These varieties (MTU 5295, CR 266-407-4, RP 1015-45-114-1, MO 6, MO 7, M 66 B-45-1, MTU 5194 and RP 2695-5-8-31) were individually crossed with Taichung Native 1, a dwarf high yielding variety from Taiwan which is highly susceptible to BPH. The F_1, F_2 and F_3 progenies of the eight crosses were evaluated. The F_1 seedlings were screened by the bulk seedling test, tiller test and honeydew experiment. In each cross, 30 F_1 seedlings were subjected to the bulk seedling test, nine F_1 plants for the tiller test and three F_1 plants for honeydew experiment. The F_2 seedlings were screened using bulk seedling test and tiller test. For bulk seedling test, about 200 seedlings and for the tiller test, nine plants in each cross were used. The F_3 seedlings were screened using bulk seedling test only for which about 100 seedlings in each progeny were used.

The F_1 plants of all the eight crosses were resistant in all the three screening tests indicating that resistance in all the resistant types is governed by dominant gene. The F_2 populations of all the eight crosses

segregated into resistant and susceptible plants. X^2 analysis revealed that there was a good fit to the 3:1 ratio for resistance and susceptibility. The F_2 results thus revealed that a single dominant gene governed resistance in each of the eight resistant types.

F_3 analysis was done in order to confirm the F_2 results. In each of the eight crosses, nine F_3 families obtained from resistant F_2 plants were subjected to bulk seedling test. The F_3 progenies were either homogenous or heterogenous for resistance. The segregating F_3 lines comprised of resistant and susceptible seedlings in the 3:1 ratio. The F_3 analysis thus confirmed that a single dominant gene confers resistance in each of the resistant types.

In order to study the allelic relationships between the resistance genes, six among the eight resistant types selected based on diverse origin were crossed among themselves in all possible combinations. The six types selected were MTU 5295, CR 266-407-4, RP 1015-45-114-1, MO 6, MO 7 and M 66 B-45-1. The F_1 plants were screened using bulk seedling test, tiller test and honeydew experiment. The F_2 populations were screened using bulk seedling test and tiller test.

All the F_1 plants were resistant in the three screening tests in all the 15 cross combinations. The F_2 populations were homogenous for resistance in all these combinations. Since there was no segregation in the F_2 progenies, there was no scope for F_3 analysis. Based on these results it has been concluded that the same dominant gene governs resistance in all the six resistant types i.e., all these six types are isoallelic for BPH resistance.

Two dominant genes governing BPH resistance have been identified till date and they are Bph1 and Bph3. In this study, MO 7 evolved from the cross IR 1539 x Triveni holds a dominant gene for resistance. IR 1539 is a variety evolved from IR 24//Mudgo/IR 8. "Mudgo" and IR 1539 carries Bph1 for resistance. But in the present study Mudgo was not found to be resistant. The variety "RatuHeenati" reported to carry Bph3 gene for resistance was also not found resistant in these studies. Hence it is assumed that MO 7 carries a dominant gene for resistance other than Bph1 and Bph3. All the six types used in genetic analysis are isoallelic and hence all of them carry the same new dominant gene.

The F_3 generation of the first set of eight crosses and the F_2 generation of the second set of 15 crosses could be advanced to identify new types combining BPH resistance

with desirable productivity characters. Resistance to the local biotype of BPH can be incorporated into the locally acceptable but susceptible high yielding varieties through recombination utilizing the resistant types identified in the present study. From among the 30 types identified as resistant, only eight were used for genetic analysis. The remaining types can also be subjected to genetic analysis to identify still newer sources of resistance.

The present study has thus made available several types resistant to the local biotype of BPH and also enabled the location of a new dominant gene conferring resistance to this biotype. These results and the materials made available can form the basis for a more effective breeding approach for BPH resistance in this region.

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* Originals not seen

ENETIC ANALYSIS OF BROWN PLANTHOPPER RESISTANCE IN RICE

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ABSTRACT

The Brown planthopper (BPH), Nilaparvata lugens (Stal), has become a serious threat to rice production throughout Asia. Very extensive losses have occurred in India, Indonesia and the Philippines. The most severe outbreak in India occurred in Kerala during 1973-74 in 'Kole' lands of Trichur district and 'Kuttanad' area of Kottayam and Alleppey districts. Although insecticides provide effective control, this approach is expensive and creates problems of environmental pollution. Resistant varieties can provide protection and insurance against this insect pest at no extra cost and with no danger from chemical residues. Very little work has been done in Kerala to identify sources of resistance to the local biotype of BPH and on the genetic basis of BPH resistance. The major objectives of the present investigation were to identify sources of resistance to BPH and to conduct genetic analysis and understand the mode of inheritance of BPH resistance.

One hundred and nine rice types were studied for their reaction to BPH through the bulk seedling test at the seedling stage and tiller test and honeydew experiment at the tillering stage. Out of them 41 were found to be resistant, 22 moderately resistant, 13 moderately susceptible

and 33 highly susceptible. In the tiller test, 31 out of the 41 resistant varieties were resistant, nine moderately resistant and one moderately susceptible. The thirtyone types found resistant under tiller test were subjected to honeydew experiment, out of which 30 were found to be resistant and one was moderately resistant.

The inheritance of resistance was studied in eight types selected from among the 30 types proved to be resistant in all the three tests. They were crossed with the susceptible variety TN1 and the F_1, F_2 and F_3 generations were studied by bulk seedling test, tiller test and honeydew experiment. F_1 seedlings were also screened by bulk seedling test, tiller test and honeydew experiment. The F_2 progenies were screened by the bulk seedling test and tiller test. The F_3 seedlings were screened by bulk seedling test only. The F_2 and F_3 progenies were scored separately as resistant and susceptible types and the observed segregation ratios were tested against the expected by applying the test of goodness of fit.

The F_1s of all the eight crosses were resistant indicating that resistance in each of the eight types was governed by dominant gene. The F_2 populations of all the eight crosses segregated in the ratio of 3 resistant : 1 susceptible indicating that a single dominant gene governed resistance in

each of the eight resistant types. F_3 breeding behaviour of the nine F_2 resistant plants from each of the eight crosses confirmed the monogenic control of resistance over susceptibility. Two dominant genes Bph1 and Bph3 were identified at IRRI (Bph1 in variety Mudgo and Bph3 in RatuHeenati). In the present study, Mudgo containing Bph1 and RatuHeenati with Bph3 gene were not resistant. Hence it is assumed that the dominant resistant gene identified in the present study is neither Bph1 nor Bph3.

Diallele crosses were made between six resistant types selected based on diverse origin. The F_1 and F_2 progenies of the 15 combinations were studied to get information on the allelie relationship between the resistance genes. The F_1 progenies of all the crosses were resistant and the F_2 progenies were homogeneous for resistance. This lead to the conclusion that all the six types have the same dominant gene for resistance. All the six resistant types were isogenic and hence all of them are expected to carry a dominant gene for BPH resistance other than Bph1 and Bph3.

The present study has thus made available several types resistant to the local biotype of BPH and also enabled the location of a new dominant gene conferring resistance to this biotype. These results and the materials made available can form the basis for a more effective breeding approach for BPH resistance in this region.