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Evaluation of Rice Genotypes of Sikkim and Tripura for Resistance to Brown Planthopper, *Nilaparvata lugens* (Stal)

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A B S T R A C T

Studies were undertaken to evaluate the rice genotypes of Sikkim and Tripura for their resistance against brown planthopper (BPH) under glasshouse conditions. Among 74 rice genotypes phenotyped, a genotype (AC-39843) was considered as resistant and two other genotype (AC-39842 and AC-39877) of Tripura were categorized as moderately resistant to BPH. To understand their mechanism of resistance, resistant genotypes were evaluated for different parameter of antixenosis and antibiosis. The antixenosis and antibiosis studies in terms of nymphal setting preference, per cent unhatchability of eggs, nymphal survival and development, honeydew excretion, probing mark test, plant dry weight loss and defence enzymes (Peroxidase, polyphenol oxidaseand catalase) indicated that these genotypes showed confirmation of resistance to BPH compared to susceptible check TN 1. Among resistant genotypes, AC-39843 recorded lowest sugar content followed by AC-39842 and AC-39877 compared to TN1. Total phenol content in AC-39843 was highest followed by AC-39877 and AC-39842. Resistant genotypes found in the study could be used as new resistant donors and utilized in resistance breeding programme against brown planthopper in rice.

Introduction

'Rice is life' describes the importance of rice in human diet. It is one of the world's most important food crops and is infested by about 800 species of insect pests in both field and storage (Barrion and Litsinger, 1994).Among the insect pests, brown plant hopper (BPH), *Nilaparvata lugens* (Stal.) (Homoptera: Delphacidae) is one of the most economically important insect pest which cause severe damage, where both nymphs and adults suck the plant sap directly andindirectly transmit viruses such as ragged stunt and grassy stunt (Khushand Brar, 1991). At early infestation, round and yellow patches appear, which soon turn brownish due to the drying up of the plants which is called as 'hopper burn', and

results in huge yield loss ranging from 10-75 percent. A large number of insecticides including chlorinated hydrocarbons, organophosphates, carbamates, and systemic pyrethroids have been used for management of BPH. But in order to provide the long lasting strategy host-plant resistance is an important option. Development of resistance rice cultivars through host plant resistance is generally considered to be the most economic and effective way for controlling BPH population. A total of 35 major BPH-resistance genes have been identified from cultivated rice and wild *Oryza* species (Wang *et al.,* 2018). Many rice varieties with resistance to plant hopper have been developed and released to the farmers for commercial cultivation, however the situation become alarming when the resistance of these new varieties diminished because of apparent selection of pest. In order to manage this pest, chemical method is mostly used with the associated problems like insect resistance to insecticide, resurgence, destruction of natural enemies etc. Hence, ensuring the genetic resistance of host plants is the most effective and environmentally-friendly approach for the BPH management. In the quest for identifying BPH resistant genes, Sikkim and Tripura rice genotypes were selected because, being land races they might be have the large pool of BPH resistant genes.

Materials and Methods

Plant material and Insects

A total of 74 (seventy four) rice genotypes of Sikkim and Tripura were collected from ICAR-NRRI Gene Bank along with TN1 as standard susceptible check, Ptb33 and Salkathi as resistant checks. The BPH insects were field collected and were maintained on Taichung Native 1 (TN1, a susceptible *indica* variety) under net house of crop protection division of ICAR-NRRI Cuttack.

Phenotyping for BPH resistance

Screening of 70 landraces of Sikkim and Tripura rice accessions against brown plant hopper (BPH) were done as per Qiu *et al.,* (2010). A bulk seedling test was conducted to evaluate BPH resistance. The pre-germinated seeds were sown as per standard seed box screening techniques at National Rice Research Institute, Cuttack (20°45' N latitude, 85°93′ E longitude and 36 m altitude). Well germinated seeds were shown at 5×1cm apart plastic tray in rows at equal distance with 20-25 seedlings of each genotype along with resistance checks, Ptb33 and salkathi and susceptible check TN1.The 2nd instar BPH nymphs were released in the screening trays containing 10-12 days old seedling (third-leaf stage) with almost 10 nymphs per seedling. Phenotypic values for the individual plants were recorded on a scale on 0–9 when all plants of susceptible control TN1 were died. This was done following the Standard Evaluation System (SES) for rice (IRRI, 2013).

Antixenosis

Nymphal setting preference

Method nymphal setting preference was followed as per the method described by Heinrichs *et al.,* (1985). From the results of phenotyping, only resistant genotypes along with TN1 (susceptible check) and Ptb33 (resistance check) seeds were sown in 50 x 40 x 7 cm plastic tray. After 10-12 days, two to three seedlings were transplanted in single earthen pot containing puddled homogeneous soil in circular fashion and TN1 seedlings in the centre. Four replicates were maintained. After 7-9 days of transplanting, 2nd instar BPH nymphs were released by gently tapping over seedlings in such a way that approximately 10 nymphs settled on each seedling and pot was covered with plastic Mylar cage. Number of

nymphs settled on each seedling was observed and recorded at 1, 2, 6, 12, 24, 48 and 72 h after infestation. The seedlings were disturbed after each count for reorientation of nymphs on seedlings.

Ovipositional response (Total fecundity)

It was carried out as per method of Reddy *et al.*, (2005). The well germinated seedlings of resistant rice genotypes as well as susceptible check TN1 and resistant check Ptb33 were transplanted in 500-600 ml plastic pots filled with puddled soil. For each genotype, four replications were maintained. After 30 days, the plants were washed and cleaned by removing dried and excess leaves for convenient oviposition. Plants were well covered with mylarcages with ventilating windows. Three gravid female (seven days old) was released with the help of an aspirator into the cage and the open end of the tube was covered with a muslin cloth and tied with a rubber band.

The females were removed five days after release. The plants were observed for nymphal hatching. The number of hatched nymphs were recorded and removed from the plant. After all the eggs were hatched or when nymphs stop coming out (after 15-20 days of adult release) the plants were cut at the base and examined under stereo zoom microscope (Nikon SMZ 745T), total number of egg masses and number of unhatched eggs were recorded.

Unhatched eggs were expressed as percentage of total, which is sum of number of nymphs counted and the number of unhatched egg.

Total fecundity = Number of emerged nymphs + Number of unhatched eggs

Number of unhatched eggs was expressed as percentage of total, which is sum of the number of nymphs emerged and number of unhatched eggs. This was given as follows,

$$\text{Per cent unhatched eggs} = \frac{\text{Number of unhatched eggs}}{\text{Number of nymphs Emerged + Number of unhatched eggs}} \times 100$$

Antibiosis (Biochemical)

Honey dew excretion method

Adult feeding as indicated by quantity of honeydew excreted was measured using the method developed by Pathak (1970). The seeds were sown in 500 ml plastic pots filled with homogenized puddled soil. Two seedlings were planted in each pot and retained only one healthy seedling after 5-6 days. For each genotype, four replications were maintained.

A small hole was made in the middle of Whatman number 1 filter paper (9 cm diameter) and a longitudinal incision was made from the margin towards centre of the hole. Bromocresol green solution (0.02%) in ethanol was taken in a petridish and the filter paper were dipped in it and then shade dried. Card board sheets were taken and cut into square shapes of 12X12 cm and a hole was made in the middle of the square. One month old seedlings were inserted through the hole and the card board squares were kept at the base of the plant and the hole was plugged with non-absorbent cotton. The treated filter paper circles were placed on the card board at the base of the plant. Small plastic cup without lid was taken and a small hole was at the base of the cup and the plants were inserted through the hole and the inverted cups were placed on the filter paper.

The honey dew excretion method of adults for feeding was carried out by five fresh female hoppers pre-starved for 4h were released into

chamber to feed on each test culture along with the resistant (Ptb 33) and susceptible (TN1) check. Four replications were maintained. The BPH adults were allowed to feed for 24 hours at the base of the stem. When the honeydew excreted by BPH comes in contact with the filter paper treated with Bromocresol green solution, spots with blue tinged margin were formed. Then the filter papers were taken out and the area of the spots were measured by graph paper method. The area of all the honeydew spots were traced on a millimetre square graph paper and the number of squares within the spots were counted. The area of all the honey dew spots was added and honeydew excretion was expressed as mm^2 per 5 females**.**

Probing mark test

It was carried out as per the method suggested by Natio (1964). For this purpose, seeds of identified resistant rice genotypes and checks (TN1 and Ptb33) were germinated separately in petridishes. Germinated seeds were sown in plastic trays containing well puddled soil. After 30 days, the seeding of each genotype was washed thoroughly with water and then transferred individually into 15 cm long test tubes containing a few drops of water. Three emerged female were introduced individually into each test tube and test tubes were plugged with sterilized cotton swab. The female was allowed to make feed on the seedling for one day (24 hrs). Thereafter, the seedlings were taken for staining in another tube containing 1.0 per cent erythrosine dye aqueous solution. Insect probing marks stained thereby counted visually after 30 minutes of staining.

Nymphal survival and development period

Method of Heinrichs *et al.,* (1985) was followed. Two seedlings per pot were transplanted in well puddled soil in a pot and four replications were maintained for each genotype. After 30 days, the resistant genotype along with checks were enclosed with glass chimney for each treatment (8 cm Dia). Thirty, 1st instar nymphs of BPH were released in each genotype.

The plants were observed daily and the number of nymphs that reached adulthood are counted and removed. The percent nymphal survival was calculated by

$$\% \text{ Nymphal survival} = \frac{\text{Number of emerged adults}}{\text{Number of released nymphs}} \times 100$$

Number of days required by nymph to turn into next instars was also recorded. On the basis of nymphal survival and development period, growth index (GI) of BPH on each genotype was calculated as follows

$$\text{Growth Index (GI)} = \frac{\% \text{ nymphs survived on test culture}}{\text{Development period of nymphs on test culture}}$$

Functional plant loss index (FPLI)

The well germinated seedlings of selected rice genotypes as well as checks, (TN1 and Ptb33) were transplanted in 500ml plastic pots filled with well puddled soil. Four replications were maintained of each genotype. To study the level of tolerance on 30-day-old seedlings, 50 1st instar nymphs were introduced onto each genotype and covered with glass chimney. Resistant as well as check genotypes were maintained without releasing BPH nymphs were served as control.

When the plant started to wilt, the brown plant hoppers were collected from each genotype individually in the test tube. The collected BPH insects were dried for 48h in oven and weighed. Simultaneously the infested and uninfested plants were removed from pots along with their root system and washed

thoroughly. Washed plants were air-dried for 3h under room temperature, then oven dried at 70^0 C for 60h and weighed the functional plant loss index (FPLI) and plant dry weight loss per mg of insect dry weight were calculated for all rice genotypes using the formulas of Panda and Heinrichs (1983) as indicated follows,

$$FPLI = 1 - \frac{\text{Dry weigh of infested plant}}{\text{Dry weigh of uninfested plant}} \times 100$$

Plant dry weight loss per mg of *N. lugens* dry weight produced = (Dry weigh of uninfested plant - Dry weigh of infested plant / Dry weigh loss per mg of *N. lugens* progeny on infested plant)

Results and Discussion

Phenotyping

Of the phenotyped genotypes of Sikkim and Tripura, into 5 major categories based on their reaction against BPH as shown in below table 3.(Only one genotype of Tripura collection (AC-39843) was with SES score of 3 and damage percentage of 25%; it was classified as Resistant (R); whereas, other two genotype of Tripura (AC-39842 and AC-39877) were with plant damage score of 5 and damage percentage of 47.82% and 41.17%, respectively; classified under moderately resistant category (MR). The TN1 (Susceptible check) exhibited plant damage score of 9 with damage percentage was 100% and it was categorized as highly susceptible; whereas, standard resistant checkPtb33 with score 1 and damage percentage 12% categorized as highly resistant to brown plant hopper

In recent years, BPH infestation on rice is on increasing trend. Host plant resistance is a major economic and desirable practice for the management of BPH (Chelliah, 1985). Resistant rice varieties can play a complementary role in minimizing insecticide use and to promote biological control in tropical rice (Way and Heong, 1994). In many instances, resistant cultivars synergize the effect of biological control agents that suppress pest population.

The release of resistant varieties by the International Rice Research Institute Las Bonos, Phillipines beginning with IR 26 in 1973 provided good control of BPH. Since then large number of resistant sources have been identified for planthoppers.

Systematic evaluation of the world collection of *Oryzasativa* began in 1967 and by 1986, 400 accessions out of 50,000 accessions screened and identified having resistance to *N. Lugens* (Rapusas and Heinrichs, 1987).

Our results did not corroborate the findings of Gajbhiye *et al.,* (2017) who reported that a total of 22 rice accessions of *O. latifolia were* categorized as highly resistant, 7 accessions *O.officinalis* were categorized as moderately resistant, 6 accessions were categorized as susceptible and remaining 14 accessions and TN1were categorized as highly susceptible. Reason could be due to in the present findings we used *O.sativa* compared to wild species like *O. latifolia* and *O.officinalis.* Other studies which support present findings are of SiddeG owda (2009) and Sidde Gowda and Gubbaiah (2009) who screened 14,190 accessions of rice under Planthopper screening (PHS), National screening nursery (NSN) and Germplasm evaluation against major pests (GEMP) and identified 386 donors processing varied degree of resistance to BPH. Rice cultivars IET 7575, IET 8116, IET 8110, IET 9912, IET 9873 and BPT 2217 were identified as brown planthopper resistant cultivars (Gubbaiah and Revanna, 1992; Shivamurthappa, 1993).

Antixenosis

The major mechanisms involved in host plant resistance are antixenosis, antibiosis and tolerance (Painter, 1951). The utilization of plant's own defense mechanisms is an attractive area of researchall over the world to manage crop pests. The mechanisms of resistance need to be studied for ascertaining the degree of resistance among plants and it is essential for the development of durable resistant varieties. These resistant factors are heritable and they operate in a concerted manner to render plants unsuitable for insect pests. The concept of resistance mechanisms could be useful to entomologists and breeders as they work together to develop varieties with most effective type of resistance against pest population (Heinrichs *et al.,* 1985).In the present study, Sikkim and Tripura rice genotypes which were resistant to BPH in glasshouse were further subjected to determine the mechanisms of resistance and the results of these studies are discussed hereunder.

Nymphal settling preference:

The resistant rice genotypes were screened for nymphal settling preference to know the antixenosis basis of resistance mechanism of rice genotypes. Out of 74 rice genotypes of Sikkim and Tripura, 3 resistant genotypes including standard checks TN1 and Ptb 33 were selected to study the nymphal setting preference of brown planthopper. The average nymphal settling preference score of rice genotypes were recorded and shown in Table 4.

There was significant among rice genotypes tested at all the time hours tested ($P<0.0001$). The average nymphs settled on resistant genotypes, AC-39843 (4.38), AC-39842 (6.19) and AC-39877 (6.24) was on par with Ptb33 (6.19) and were significantly different from susceptible check TN1 which recorded highest average nymphal settling (15.57). Similar trend of lower number of nymphal settling was also recorded on resistant genotypes at different time interval (Table 4).

Similar to findings of the present study, Soundrararajan *et al.,* (2002) studied nymphal setting preference on doubled haploid lines at 12, 24, 48 and 72 h after release and it was 2.18, 2.72, 3.61 and 4.36 nymphs per seedling, respectively. The highest population was observed in the susceptible check TN1 (4.34 nymphs) and the lowest was on resistant check Ptb 33 (1.88 nymphs).Likewise, studies of Bhanu *et al.,* (2014) shown that highly resistant rice culture, MTU IJ 206-7-4-1 recorded least number of nymphs (3.22) while TN1 recorded the highest (12.01) and studies of Reddy *et al.,* (2016) also found that resistant entries, IET-23620 and IET-23665 exhibited least number of BPH nymphs settled per plant (1.3 nymphs/ plant) compared to TN1 which recorded the highest number of nymphs (25.7 nymphs/ plant), thus both the studies corroborating the current findings.

Ovipositional response (Total fecundity)

Oviposition on plants by an insect greatly depends on the host plant preference. The present study revealed less number of eggs laid on the resistant genotypes as compared to susceptible check TN1. There was significant difference among the tested genotypes. With respect to fecundity of BPH on test genotypes, least number of eggs were laid on resistant check Ptb 33 (39) followed by AC-39877 (110.33) and AC-39843 (156.33). But eggs laid in another resistant genotype AC-39842 (199.67) was on par with the susceptible check, TN1 (178.67). But, least number of nymphs emerged from Ptb 33 (32) which was on par with AC-39842 (57.67), AC-39843 (38.67) and AC-39877 (43.67). TN1 had highest number of emerged nymphs (121).

Over all, least number of eggs was laid and least number of nymphs was hatched in the resistant genotypes as compared to susceptible check TN1, thus indicating their non-preference for egg laying (Table 5).

The mean number of nymph emerged was significantly high in susceptible check TN1 (121.00), than in all the tested genotypes and Ptb33. Among resistant genotypes, the nymphal emergence value was ranged from 32.00 to 57.67. The resistant check Ptb33 had the nymphal emergence value of 32.00. The lowest number of nymph emergence was found in resistant rice genotypes like AC-39843 (38.67) followed by AC-39877 (43.67) and AC-39842 (57.67), and it was little higher than Ptb33 (32.00) but lower than susceptible check TN1 (124.00).

The percent unhatched egg in resistant and moderately resistant genotypes was ranged from 57.75 to 76.32 per cent, whereas it was 16.67 per cent and 32.75 per cent in resistant check Ptb33 and susceptible check TN1, respectively. The highest percentage of unhatched eggs was found in the genotype AC-39843 (76.32 %) followed by AC-39842 (71.56 %) and AC-39877 (57.75 %).

The increasing percentage of unhatched (unfertile) eggs in resistance genotypes means, biochemical factors of resistant plants might be increased which exerted adverse effect on fertility of BPH eggs.

Similar observations were also made by Senguttuvan *et al.,* (1991) and Alagar *et al.,* (2007), where in, they reported less number of eggs and higher percent of unhatched eggs on Ptb 33 compared to susceptible check TN1. Wu *et al.,* (1986) observed that, the resistant accessions were non-preferred and *N. Lugens*caged on resistant accessions had low food, fecundity and consequently low populations. Oviposition of BPH was significantly high on susceptible check genotype TN1 and low on resistant genotypes. All the resistant genotypes exerted adverse effect on the oviposition of BPH.

Antibiosis (Biochemical)

Honey dew excretion method

Screened resistant and moderately resistant rice genotypes along with standard checks TN1 and Ptb 33 were selected to study brown planthopper honey dew excretion response and the amount of phloem in the honey dew excreted by the insect in the genotype was measured in mm^2units. There was a significant difference among the plant differentials. All the selected resistant genotypes exhibited average honeydew excretion values which varied from 219.67 to 284.67 mm^2 per three female in 24 h (Table 6), which was significantly lower than the susceptible check TN1.

The highest feeding rate was observed in susceptible check TN1 (776.67 mm^2/three female). The resistance genotypes AC-39843 (219.67) had least honey dew area among the resistant genotypes followed by AC-39877 (331.33) and AC-39842 (284.67) but not with Ptb 33 resistant check. Resistant check Ptb33 had lowest honeydew excretion of 76.00 mm^2 which was lower than other resistant rice genotypes tested.

Measuring honeydew excretion is a tool for assessing antibiosison feeding activity of sucking insects on resistant and susceptible varieties (Auclair, 1958). In the present study, number of honey dew secreted area by BPH was more and less in Ptb 33 and other resistant genotypes tested. Similar results were obtained by Paguia *et al.,* (1980) where they found more area of honeydew excretion on filter papers in susceptible variety (TN1) compared to resistant varieties (Mudgo and ASD 7).

Table.1 Phenotyping of rice germplasm of Tripura against BPH

Sr. No	Rice accession	TP	DP	DP%	Scoring	Rating
1	AC-39842	23	11	47.82	5	MR
2	AC-39843	20	5	25	3	R
3	AC-39844	20	16	80	9	HS
4	AC-39845	20	19	95	9	HS
5	AC-39846	27	21	77.77	9	HS
6	AC-39847	23	18	78.26	9	HS
7	AC-39849	24	24	100	9	HS
8	AC-39850	23	22	95.62	9	HS
9	AC-39851	21	21	100	9	HS
10	AC-39852	20	20	100	9	HS
11	AC-39853	14	14	100	9	HS
12	AC-39854	24	24	100	9	HS
13	AC-39855	12	12	100	9	HS
14	AC-39856	10	9	90	9	HS
15	AC-39857	14	14	100	9	HS
16	AC-39858	18	17	94.44	9	HS
17	AC-39859	28	24	85.71	9	HS
18	AC-39860	30	26	86.66	9	HS
19	AC-39861	25	25	100	9	HS
20	AC-39862	24	24	100	9	HS
21	AC-39863	25	25	100	9	HS
22	AC-39864	24	24	100	9	HS
23	AC-39866	24	23	95.83	9	HS
24	AC-39867	24	23	95.83	9	HS
25	AC-39868	25	25	100	9	HS
26	AC-39869	20	20	100	9	HS
27	AC-39870	15	10	70	7	MS
28	AC-39871	24	21	87.5	9	HS
29	AC-39872	25	23	92	9	HS
30	AC-39874	25	24	96	9	HS
31	AC-39875	23	23	100	9	HS
32	AC-39876	20	18	90	9	HS
33	AC-39877	17	7	41.17	5	MR
34	AC-39878	19	19	100	9	HS
35	AC-39879	19	17	89.84	9	HS
36	AC-39880	20	14	70	7	MS
37	AC-39881	15	10	70	9	HS
38	AC-39882	10	10	100	9	HS
39	AC-39883	28	28	100	9	HS
40	AC-39885	23	15	65.21	7	MS
41	AC-39886	15	10	75	9	HS
42	AC-39887	22	22	100	9	HS
43	AC-39888	23	23	100	9	HS
44	AC-39889	22	20	90.9	9	HS
45	AC-39891	23	23	100	9	HS
46	TN1	25	25	100	9	HS
47	Ptb 33	25	3	12	1	HR

Table.2 Phenotyping of rice germplasm of Sikkim against BPH

Sr. No	Rice accession	TP	DP	DP%	Scoring	Rating
1	AC-39737	23	17	73.91	9	HS
2	AC-39738	24	24	100	9	HS
3	AC-39739	12	12	100	9	HS
4	AC-39740	15	10	70	7	MS
5	AC-39741	10	10	100	9	HS
6	AC-39742	13	13	100	9	HS
7	AC-39744	11	11	100	9	HS
8	AC-39746	16	13	81.25	9	HS
9	AC-39747	20	20	100	9	HS
10	AC-39750	14	14	100	9	HS
11	AC-39751	16	11	68.75	7	MS
12	AC-39752	23	23	100	9	HS
13	AC-39753	28	18	64.28	7	MS
14	AC-39754	17	17	100	9	HS
15	AC-39756	21	15	71.42	9	HS
16	AC-39757	24	22	91.66	9	HS
17	AC-39759	15	15	100	9	HS
18	AC-39760	26	13	50	5	MS
19	AC-39761	25	24	96	9	HS
20	AC-39762	15	12	80	9	HS
21	AC-39769	22	21	95.45	9	HS
22	AC-39770	25	21	84	9	HS
23	AC-39772	21	15	71.42	9	HS
24	AC-39776	17	15	88.23	9	HS
25	AC-39777	14	13	92.85	9	HS
26	AC-39780	18	15	83.33	9	HS
27	AC-39781	24	24	100	9	HS
28	AC-39782	15	15	100	9	HS
29	AC-39784	24	23	95.83	9	HS
30	TN1	25	25	100	9	HS
31	Ptb 33	25	3	12	1	HR

Note: TP: Total plant, DP: Dead plant, HS: Highly Susceptible, MS: Moderately Susceptible, MR: Moderately Resistant, HR: Highly Resistant, R: Resistant

Table.3 Summary of BPH reaction of rice germplasm of Sikkim and Tripura

Average plant damage score (Range)	Rice germplasmof Sikkim and Tripura	Rating
0-1	0	Highly Resistant
1-3	1-Tripura	Resistant
3-5	2-Tripura	Moderately Resistant
5-7	1Tripura and 1 Sikkim	Moderately Susceptible
7-9	70 Sikkim and Tripura	Highly Susceptible

Table.4 Settling behavior of BPH nymphs on test genotypes at different time interval

Rice Genotypes	Number of nymphs settled							Avg. No. of nymphs on test genotypes
	1hr	2hr	6hr	20hr	24hr	48hr	72hr	
AC-39842	6.00^{C}	7.67^{B}	6.00^{B}	7.00^{BC}	5.67^{B}	6.00^{B}	5.00^{B}	6.19^{AC}
AC-39843	3.67^{C}	5.00^{B}	5.67^{B}	5.67^{C}	2.67^{C}	5.00^{B}	3.00^{B}	4.38^{C}
TN1	18.00^{A}	18.00^{A}	15.67^{A}	13.67^{A}	15.00^{A}	14.67^{A}	14.00^{A}	6.24^{B}
AC-39877	12.00^{B}	5.67^{B}	3.67^{B}	9.67^{B}	4.00^{BC}	4.67^{B}	4.00^{B}	15.57^{A}
Ptb33	6.00^{C}	9.00^{B}	7.67^{B}	6.00^{C}	4.67^{B}	7.00^{B}	3.00^{B}	6.19^{AC}
F value	21.013	26.29	21.21	23.85	182.25	54.75	54.25	126.06
***P* value**	0.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table.5 Ovipositional response of three BPH on resistant genotypes

Sr. no.	Rice genotypes	Fecundity (No.)	No. ofnymph emerged	% unhatched eggs
1	**AC-39842**	199.67^{A}	57.67^{B}	71.56^{A}
2	**AC-39843**	156.33^{AB}	38.67^{B}	76.32^{A}
3	**AC-39877**	110.33^{B}	43.67^{B}	57.75^{AB}
4	**TN1**	178.67^{A}	121.00^{A}	32.75^{BC}
5	**Ptb 33**	39.00^{C}	32.00^{B}	16.64^{C}
6	**F value**	23.875	8.260	16.651
7	**P value**	<.0001	0.0033	0.0012

Table.6 Honey dew experiment of BPH on different test genotypes

Sr. No.	Treatment	Honey dew area (mm^2)
1	AC-39842	284.67^{BC}
2	AC-39843	219.67^{BC}
3	AC-39877	331.33^{B}
4	TN1	776.67^{A}
5	Ptb33	76.00^{C}
6	F value	9.537
7	P value	<.0001

Table.7 Probing mark test of three female BPH on different test genotypes

Sr. No.	Resistance rice genotypes	Number of probing mark
1	AC-39842	51.67^{D}
2	AC-39843	68.67^{C}
3	AC-39877	52.67^{D}
4	TN1	31.00^{E}
5	Salkathi	90.00^{B}
6	Ptb33	105.00^{A}
	F value	122.55
	P value	<.0001

Table.8 Nymphal survival and development period on test genotypes

Genotypes	Nymphs tested for survival and development period on resistance and susceptible genotypes							
	1st instar	Survival %	2nd instar	Survival %	3rd instar	Survival %	4th instar	Survival %
AC-39842	28.00^{B}	93.33^{B}	26.33^{A}	87.78^{A}	22.33^{B}	74.44^{B}	11.67^{B}	38.89^{B}
AC-39843	29.00^{AB}	96.67^{AB}	27.00^{A}	90.00^{A}	16.00^{C}	53.33^{C}	5.00^{C}	16.67^{C}
AC-39877	29.67^{A}	98.89^{A}	27.33^{A}	91.11^{A}	23.67^{B}	78.89^{B}	10.00^{B}	33.33^{B}
TN1	29.00^{AB}	96.67^{AB}	27.67^{A}	92.22^{A}	27.67^{A}	92.22^{A}	24.00^{A}	80.00^{A}
Ptb33	20.00^{C}	66.67^{C}	13.00^{B}	43.33^{B}	1.00^{D}	3.33^{D}	1.00^{D}	3.33^{D}
F value	182.87	182.875	54.42	54.425	546.55	546.76	364.15	364.22
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table.9 Development period and growth index (GI) of BPH on test genotypes

Sr. No.	Genotypes	Development Period	Growth Index (GI)
1	**AC-39842**	16.33^{B}	2.38^{B}
2	**AC-39843**	18.33^{AB}	0.91^{C}
3	**AC-39877**	17.00^{B}	1.96^{B}
4	**TN1**	12.33^{C}	6.50^{A}
5	**Ptb33**	19.67^{A}	0.15^{D}
6	**F value**	34.6000	270.767
7	**P value**	<.0001	<.0001

Table.10 FPLI and PD of resistant rice genotypes against BPH

Genotypes	Dry weight of BPH Uninfested Plant (gm)	Dry Weight of BPH Infested Plant (gm)	FPLI (%)	Dry weight of BPH on infested plant (gm)	PD (mg)
AC-39842	0.35^{C}	0.29^{C}	18.82^{B}	0.01^{B}	9.29^{B}
AC-39843	0.51^{AB}	0.45^{A}	12.94^{B}	0.01^{A}	5.66^{B}
AC-39877	0.44^{BC}	0.36^{B}	18.82^{B}	0.01^{AB}	8.27^{B}
TN1	0.56^{A}	0.28^{C}	49.97^{A}	0.01^{AB}	31.05^{A}
Salkathi	0.41^{C}	0.38^{B}	8.79^{B}	0.01^{B}	5.48^{B}
F value	33.969	21.905	52.905	6.385	11.713
P value	0.0004	0.0001	<.0001	0.0081	0.0009

FPLI – Functional Plant Loss Index (%)
PD – Plant dry weight loss per mg of insect dry weight produced.

Also, Kim *et al.*, (1998) reported less amount honeydew excretion on resistant cultivars. Likewise honeydew excretion was less in the high Si addition treatment (50 mg) than in the control (30 mg) as reported by Yang *et al.*, (2017).

Probing mark test

The average probing behaviour of BPH on resistant rice genotypes along with standard checks TN1, Ptb33 and salkathi are presented in (Table 7). The average number of probing marks by three adult gravid female of brown planthopper varied from 31.00 to 105.00.

There was significant difference among tested genotypes (P<0.0001). The resistant genotype AC-39842 had the average probing marks of 51.67, which was on par with AC-39877 which had 52.67 marks. Whereas, AC-39843 had 68.67 marks which was significantly different from aforementioned genotypes. The average probing mark per seedling in resistant check Ptb 33 was 105, which was significantly higher than three resistant genotypes.Among all resistant genotype tested, the genotype AC-39842 had the lowest (51.67) average probing marks per seedling. Among the checks, the lowest probing marks (31.00) were observed in TN1.Similar work has been carried out by Alagar *et al.*, (2008) who reported that, the maximum number of feeding marks were observed on resistant ARC 10550 (43.80), which was 4.52 times higher than TN1.

Nymphal survival and development period

Brown planthopper nymphal survival and development period as an indicator of antibiosis was carried out on resistant genotypes along with standard checks. All the test genotypes exhibited significant difference among themselves (P<0.0001). In the 1st instar, least nymphal survival percentage was observed in Ptb 33 (66.67) and highest was in AC-39877 (98.89). The survival percentage of 1st instar to 4th instar BPH on resistant genotypes was significantly lower than the susceptible check TN1 (96.67 to 80.00) (Table 8).

Whereas developmental period of test genotypes ranged from 12.33 to 19.67 days, and were significantly different (*P*<.0001). In TN1, nymphal survival percentage was significantly higher and developmental period was significantly lower than in all the resistant genotypes including resistant check Ptb 33. Resistant check Ptb 33 showed nymphal survival of 3.33 per cent at 4th instar, which was significantly lower than AC-39842, AC-39843 and AC-39877 genotypes and susceptible check TN1. Whereas, the developmental period of BPH on Ptb 33 was highest (19.67), which was significantly higher than 3 resistant genotypes and also susceptible check TN1.

In all the resistant genotypes tested, the genotype AC-39843 had the lowest 3rd and 4th instar nymphal survival value (53.33 and 16.67 %) followed by genotype AC-39877 and AC-39842, but it was significantly lower than the susceptible check variety TN1.

Among all the resistant genotypes tested, the genotype AC-39843 had the lower developmental period (18.33 days) followed by AC-39877 (17.00 days) and AC-39842 (16.33 days), but it was significantly higher than the susceptible check TN1 (12.33).

Survival rate determines the effect of antibiosis factors on nymphal stage (Heinrichs *et al.,* 1985). The per cent nymphal survival was found to be less on resistant genotype Ptb 33 (3.33%). Recently similar work has been reported by Jena *et al.,*(2015), where nymphal survival in all highly resistant(score 1) farmers' varieties ranged within 10.8 to 29.2% and were significantly lower than susceptible check TN1. Results Alagar *et al.,* (2007) also corroborates our finding wherein the resistant genotypes ADT 45, Ptb 33and ASD 7 had the lowest nymphal survival rate than the susceptible TN1. Similarly, Nanda *et al.,* (1997) reported very low nymphal survival of BPH in resistant varieties. Dharma and Mishra (1995) reported that the survival of BPH nymphs was less on all varieties tested, than on the susceptible check (TN1). The nymphal survival ranged between 43.30 and 83.30 per cent for most of the cultivars, except TN1, where 96.70 per cent of the nymphs survived. With respect to nymphal development, our findings supports the study of Bhanu *et al.,* (2014) who found that MTU IJ 206-7-4-1 recorded significantly prolonged development period of nymphs (26.00 days) than the susceptible check TN1 (8.48)

The growth index (GI) of BPH on different resistant genotypes was lower than susceptible check TN1. Among resistant genotypes, line AC-39843 had GI of 0.91 which was followed by AC-39877 (1.96) and AC-39842 (2.38). The lowest growth index was seen in resistant check Ptb 33 (0.15) and highest growth index was recorded in TN1 (6.50) Table 9.

Functional plant loss index (FPLI)

The Functional Plant Loss Index (FPLI) due to BPH infestation was more in susceptible genotype than in resistant genotypes and there exists significant difference among themselves. Among the resistant genotypes,

AC-39843 had lowest FPLI (12.94) followed by AC-39842 (18.82) and AC-39877 (18.82). All these genotypes were on par with each other and were significantly different from resistant and susceptible checks. The resistant check Salkathi recorded lower FPLI (8.79) (Table 10).

The plant dry weight loss per mg of insect dry weight produced was lower in Salkathi (5.48mg) followed by resistant genotypes AC-39843 (5.66 mg), AC-39877 (8.27 mg) and AC-39842 (9.29 mg) which were on par with each other. Susceptible TN1 had 31.05 mg which was significantly high as compared to other tested genotypes (Table 10).

All the resistant genotypes recorded lower FPLI compared to susceptible genotype, TN1. The present findings were in conformity with Alagar *et al.,* (2007), who reported lowest FPLI in Ptb 33 compared to susceptible genotype TN1. Further it was observed that *Oryza rufipogan* and *O. nivara* had lower FPLI compared to *O. perenis* and IR 26 (Wu *et al.,* 1986).

Our results found the resistant genotype for the management of BPH by suppressing the feeding behavior, growth and longevity of BPH insects. This can in turn facilitate the development of BPH-resistant rice varieties in the future and help limit pesticide use. Resistant genotypes found in the study could be used as new resistant donors and utilized in resistance breeding programme against brown planthopper in rice.

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