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Artículos

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Evaluación de niveles de antixenosis y antibiosis en genotipos de arroz contra *Sogatella furcifera* (Hemiptera: Delphacidae)

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Abstract: White-backed planthopper, *Sogatella furcifera* Horváth (Hemiptera: Delphacidae) is a migratory and serious pest of rice crop worldwide including Pakistan. The current experiment was carried out to assess the antixenosis and antibiosis level of fifteen rice genotypes against *S. furcifera* under greenhouse conditions. In antixenosis studies, proportion of nymphs and adults settled was recorded in relation to control. Less preferred varieties by nymphs were RPP49 (3.80), N22 (5.60), IR 64 (6.20), IR 72 (6.60), Basmati Pak (6129) (5.40), and Super Basmati (5.00) as compared to TN1 (12.00). Lower number of eggs were laid on RPP49, N22, IR 64, Super Basmati and PKBB 8. Based on feeding marks the genotypes ranked from highest to lowest as RPP49, N22, IR 64, IR 72 and Basmati Pak. In antibiosis tests, RPP49, N22, IR64, IR 72, Super Basmati and Basmati Pak varieties performed well as compared to TN1. Minimum feeding rate (47.8 mm^2) was recorded on RPP49 followed by N22, IR 64, IR74, Basmati Pak, Super Basmati, PKBB 8, PK 10684 and PK 10436 as compared to TN1(470.8 mm^2). The results revealed that RPP49 emerged as the new resistant source against *S. furcifera*. Super Basmati, Basmati Pak have shown a moderate level of resistance while PKBB 8, PK 10684 and PK 10436 are new varieties with a moderate level of resistance

to *S. furcifera* which can be used as resistance source in breeding programs against *S. furcifera.*

Keywords: Controlled conditions, *Oryza sativa* , Resistance level, White-backed planthopper.

Resumen: La falsa chicharrita del arroz, *Sogatella furcifera* (Horváth) (Hemiptera: Delphacidae) es una plaga migratoria y grave para los cultivos de arroz en todo el mundo, incluso Pakistán. El presente experimento se llevó a cabo para evaluar el nivel de antixenosis y antibiosis de quince genotipos de arroz contra *S. furcifera* en condiciones de invernadero. En los ensayos de antixenosis, la proporción de ninfas y adultos asentados se registró en relación con el grupo control. Las variedades menos preferidas por las ninfas fueron RPP49 (3.80), N22 (5.60), IR 64 (6.20), IR 72 (6.60), Basmati Pak (6129) (5.40) y Súper Basmati (5.00) en comparación con TN1 (12.00). Se depositó un número menor de huevos en RPP49, N22, IR 64, Súper Basmati y PKBB 8. Con base en la huella de alimentación, los genotipos ordenados de mayor a menor fueron RPP49, N22, IR 64, IR 72 y Basmati Pak. En ensayos de antibiosis, las variedades RPP49, N22, IR64, IR 72, Súper Basmati y Basmati Pak obtuvieron buenos resultados en comparación con TN1. La menor velocidad de alimentación (47.8 mm^2) se observó en RPP49, seguida por N22, IR 64, IR74, Basmati Pak, Súper Basmati, PKBB 8, PK 10684 y PK 10436, en comparación con TN1(470.8 mm^2). Los resultados revelaron que RPP49 se ha convertido en la nueva fuente de resistencia contra *S. furcifera*. Súper Basmati, Basmati Pak han mostrado un nivel moderado de resistencia, en tanto que PKBB 8, PK 10684 y PK 10436 son nuevas variedades con nivel moderado de resistencia, capaces de ser utilizadas como fuente de resistencia en programas de reproducción contra *S. furcifera.*

Palabras clave: Condiciones controladas, Falsa chicharrita del arroz, Nivel de resistencia, Oryza sativa .

INTRODUCTION

Rice (*Oryza sativa* L.) is considered one of the major staple foods and is extensively cultivated on diverse ecosystems of tropical and sub-tropical regions of the world. The huge increase in world population, the gradual decrease in arable land, the water scarcity and changing environmental conditions have resulted in a serious challenge in food requirements. Among various constraints in rice production, insect pests are of great concern (Heong & Hardy, 2009). With more than 100 species of insects reported as pests in rice crops (Prakash et al., 2007), the planthoppers *Sogatella furcifera* (Horváth), *Nilaparveta lugens* (Stål.) and *Laedephax striatellus* (Fallén) are considered the most serious pest of rice throughout Asia (Cheng, 2009; Hu et al., 2015) producing important economic losses (Catindig et al., 2009). Whitebacked planthopper (*S. furcifera*), is a migratory and major delphacid hopper that attacks *O. sativa* L. in tropical Asia (Matsumura et al., 2009). First outbreak of this pest was recorded in 1980's in the southern region of Pakistan on semi dwarf varieties and the yield loss estimated was of about 60% (Mahar et al., 1978; Majid et al., 1979; Ghauri, 1979; Rehman et al., 1986); so, Punjab is the major rice growing province in Pakistan, where the yield damages may be up to 7-10% annually. Attack of planthopper causes hopper-burn which hinders the growth of rice plant and decreases crop production (Sumikarsih et al., 2019). Additionally, *S. furcifera* is known to transmit the fijivirus, the southern rice black streaked dwarf virus (SRBSDV)

(Zhou et al., 2008; Guo et al., 2013) and rice black streak dwarf virus -2 (RBSDV-2) (Zhang et al., 2008).

The indiscriminate use of insecticides to control this pest has resulted in resistance problems, pest resurgence and disruption of natural balance of rice ecosystems (Wang et al., 2014). Moreover, insecticide residues detected in Basmati rice is a serious threat for the foreign exchange commodity (Kumar et al., 2015). Use of synthetic chemical insecticides cannot be a sustainable pest management strategy. Development of resistant varieties against planthoppers is an environment friendly, economical and efficient control strategy (Li et al., 2011). These varieties will conserve natural enemies which in turn increase their efficacy (Gurr et al., 2011) and will reduce the pesticide application rates (Panda & Khush, 1995; Sharma, 2007). Hence, it is imperative to establish breeding programs to develop WBPH resistant varieties. There are three resistant parameters utilized by plants in defense of insect pests namely, antixenosis, antibiosis and tolerance (Painter, 1951). Research work on the development of resistant varieties against plant hoppers was initiated at the International Rice Research Institute, Philippines in 1970 and many varieties were screened and developed against planthoppers. Many methods to determine antixenosis and antibiosis levels among different rice genotypes were developed at IRRI (Heinrichs et al., 1985; Khan & Saxena, 1986; Misra & Misra, 1991; Eickhoff et al., 2008; Li et al., 2011). However, no detailed experiments were performed to evaluate the performance of existing rice germplasm for resistance against whitebacked planthopper in Pakistan. Keeping in view these considerations, present experiments were conducted to study their antibiosis and antixenosis levels in different rice genotypes against *S. furcifera.*

MATERIAL AND METHODS

Study site

The present studies were conducted in the greenhouses of the Rice Research Institute Kala Shah Kaku Pakistan positioned at 31°43'17" N, 74°16'14" E. The area has been under rice cultivation for a long time and several insect pests, especially the white-backed planthopper attacks on rice crop, are a serious concern in the cropping season. Use of synthetic chemicals and other modern agricultural practices has disrupted the biodiversity of insect pests in the area.

Plant material

The seeds of 15 rice genotypes PK 10684-6-1-1, PK 10436-4-2-2-1, PK 10355-13-2-1, PK 10683-12-1, PK 9966-10-1, N22, PKBB 8, Basmati Pak (6129), Super Basmati, TN (1), IR 64, RPP49, IR 72, KSK 476, KSK 480 were obtained from the Rice Research Institute, Kala Shah Kaku

Pakistan. These entries were used in different experiments to explore their antibiosis and antixenosis levels against *S. furcifera.*

Insect culture

Both adults and nymphs of white-backed planthopper were collected from rice fields at the Rice Research Institute (RRI) Kala Shah Kaku with the help of aspirators. The specimens were shifted to a susceptible rice variety (TN1) sown in pots and reared for approximately 10 generations in bottomless hopper rearing cages [60 cm (L) × 45 cm (W) × 10 cm (H)] placed on the galvanized iron tray. Potted plants were placed on these trays with 8 cm depth of water inside the cage. When the pest population increased, the plants in the rearing cages were replaced with fresh ones sown in the pots. Old plants from the rearing cages with eggs of WBPH females were used for culture maintenance in hopper rearing cages. These cages were placed in a greenhouse maintained at 28-30 °C temperature and 55-60% RH (Heinrichs et al.,1985).

Antixenosis studies

Settling behavior of nymphs

In this experiment, the test entries were sown in rows, with 3.5 cm spacing, in seed boxes (45 cm × 35 cm × 10 cm). In each row 10 seeds were sown. Each entry was replicated five times in the seed boxes. The control treatment TN1 was sown in two side rows and one in the center of the box. After 10 days of emergence, the seedlings were infested with 2nd and 3rd instars nymphs with 6-8 *per* seedling in the boxes. In order to avoid escapes, the trays were covered with nylon mesh. Settled nymphs on each seedling were counted after 1, 2 and 3 days after infestation. The results were averaged after three days. The seedlings were agitated after each count so that hopper nymphs could reorient themselves (Heinrichs et al., 1985; Sarao & Bentur, 2016).

Settling behavior of adults

For adult settling behavior studies, all the steps were the same as in nymphal experiment, however 30 days older plants were used in seed boxes. Two seedlings were sown *per* hole and the entries were replicated five times. After 30 days, 10 adult female hoppers/hill were released on the tested entries. Settled adults were counted after 24, 48 and 72 hours. Average of the replication of the three counts was compared to determine the level of antixenosis among genotypes (Heinrichs et al., 1985).

Number of eggs

In the antixenosis for adult experiment after 72 h counting, plants were cut close to the soil surface and dissected in the laboratory and the number of eggs were counted under microscope to determine level of antixenosis among different genotypes (Heinrichs et al., 1985).

Feeding marks

Probing activity for feeding was determined by counting the feeding probes or stylet sheaths by hoppers on different rice genotypes. Two adult planthoppers were placed in a parafilm sachet attached to the leaf sheath of different rice genotypes. Each entry was replicated five times. Hoppers were allowed to feed for 24 h. After that, the feeding portion of the leaf sheath about 2-2.5 cm long was cut and then dipped in 1% rhodmine solution for 10-15 minutes. The stylet sheaths were stained pink with the dye to determine the feeding marks by the pest (Heinrichs et al., 1985; Sarao & Bentur, 2016).

$$\text{(a) } Survival\ (\%) = \frac{\text{Number of surviving insects in cage}}{\text{Number of nymphs released in cage}}$$

$$\text{(b) } Egg\ hatch\ (\%) = \frac{\text{Number of nymphs}}{\text{Number of nymphs} + \text{Number of unhatched eggs}} \times 100$$

$$\text{(c) } Adult\ emergence\ (\%) = \frac{\text{Number of emerged adults}}{\text{Number of nymphs infested}} \times 100$$

$$\text{(d) Growth index} = \frac{\text{Adult emergence (\%)}}{\text{Mean developmental period (Days)}} \times 100$$

Fig. 1. Formulae used in this study

Antibiosis studies

Nymphal survival

For antibiosis experiment twenty days old plants of different genotypes were grown in pots. The plants were covered with a cage (10 cm wide and 90 cm tall) arranged in an iron tray filled with water. All the insects, parasites and predators were removed after caging the plants. In total ten first instar *S. furcifera* nymphs were placed in each cage. After 12 days plants were examined and surviving nymphs in each cage were counted. Nymphal survival was computed by the equation detailed in Fig. 1a (Heinrichs et al., 1985).

Feeding rate

Feeding rate was calculated by the quantity of honey dew secreted by hoppers while feeding on different rice genotypes. One plant of each entry was potted in earthen pot and the experiment was replicated five times. Thirty days old rice plants were used in this experiment. Whatman filter paper no. 1 was placed at the base of the plant with a hole in the center to cover stem of the rice plant. Five gravid females starved for 48 hours were placed in the specially prepared feeding chambers. The filter papers were treated with bromocresol green to indicate the honey dew secreted by plant hoppers. Filter papers were removed after 24 h and placed on the card board. Area of the honey dew secreted was measured according to Heinrichs et al. (1985) and Horgan et al. (2018).

Population growth and egg hatchability

The rate of increase of the population of *S. furcifera* on the test genotypes was determined on 7 days old seedlings. These varieties were transplanted into pots at 2-4 seedlings *per* pot and were placed in an iron tray filled with water. There are five replications and treatments were arranged in RCBD design. After thirteen days, the plants in the pots were covered with a cage. Insects, parasites and predators were removed after caging the plants and the plants were infested with five pairs (male and female) three-day old adults of *S. furcifera per* cage. Progeny was counted 30 days after infestation (Heinrichs et al., 1985; Cook et al., 1987).

After five days all the survived adults were removed from the cages with the help of the aspirator and then plants remained with the cages for further counting of the emerging nymphs and unhatched eggs. The nymphs were counted from six days after infestation until hatching was completed at 10^{th} day. After 15 days, plants were dissected and examined under microscope for unhatched eggs. Total number of eggs per treatment was calculated by adding the number of nymphs and unhatched eggs. Egg hatchability (%) was calculated by the formula showed in Fig. 1b.

Growth index

Potted plants of the test genotypes were covered with screen cages (90 cm ×10 cm) and were arranged in a RCBD (randomized complete block design) design in an iron tray filled with water. These plants were infested with ten first instar nymphs of *S. furcifera* in each cage. All the insects, parasites and predators were removed after caging the plants. Nymphs were allowed to become adults. Adult emergence was documented daily and the total number of adults emerged in each cage was calculated. Percent adult emergence was calculated as indicated in Fig. 1c.

The growth index of insects on tested cultivars was calculated as the ratio of mean growth period in days to the percentage of nymphs which develop into adults (Heinrichs & Rapusas, 1983; Cook et al., 1987; Santhanalakshmi et al., 2010). The growth index was calculated as showed in Fig. 1d.

Statistical analysis

Data was expressed as mean ± SE. Bartlett test was performed before analysis of variance and the parameters which were not normal were transformed with log10 transformation. One way and two-way ANOVA was used for the analysis of the variance. Means were separated by Tukey HSD test ($P < 0.05$) for significance differences between treatments (Sokal & Rohlf, 1995). Data was analyzed with Statistix software (version 8.1) (Tallahassee, FL).

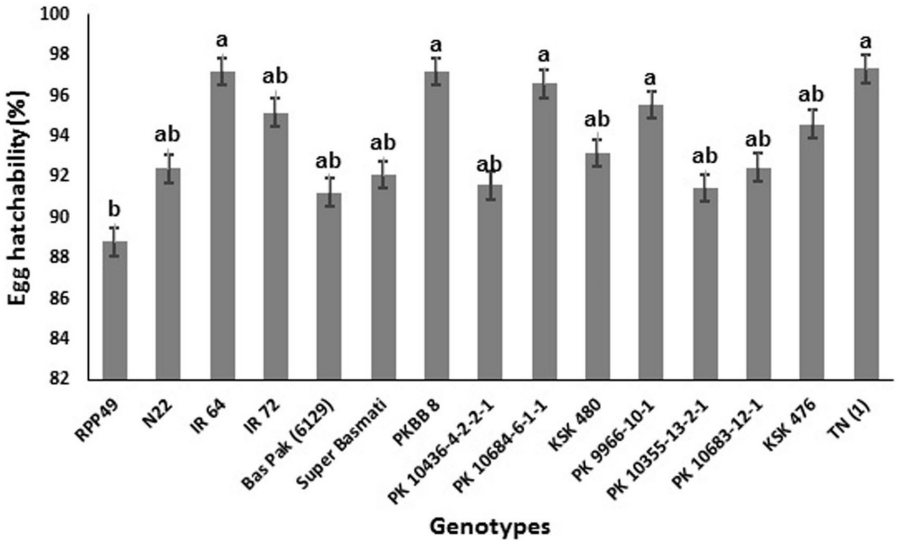

Fig. 2. Egg hatchability of *Sogatella furcifera* in different rice genotypes.
Means with different lower-case letters in each bar are significantly different at p ≤ 0.05 (Tukey's HSD test).

Genotypes	No. of nymphs	No. of adults	No. of eggs	Feeding marks
RPP 49	3.80 ± 0.37 g	4.40 ± 0.24 h	112.00 ± 3.74 h	30.8 ± 0.86 a
N22	5.60 ± 0.51 defg	4.60 ± 0.40 gh	120.00 ±2.74 h	28.8 ± 0.80 ab
IR 64	6.20 ± 0.49 cdef	5.40 ± 0.24 gh	135.80 ± 2.03 fg	26.2 ± 0.58 bc
IR 72	6.60 ± 0.24 bcdef	5.80 ± 0.20 fgh	137.00 ± 3.00 fg	23.2 ± 1.28 cd
Bas Pak (6129)	5.40 ± 0.24 efg	5.40 ± 0.24 gh	133.00 ± 3.00 g	27 ± 0.71 b
Super Basmati	5.00 ± 0.89 fg	5.60 ± 0.24 fgh	141.20 ± 2.48 fg	26.2 ± 1.02 bc
PKBB 8	6.00 ± 0.32 defg	6.20 ± 0.49 efgh	147.00 ± 3.51 ef	22 ± 0.71 de
PK 10436-4-2-2-1	6.20 ± 0.49 cdef	6.40 ± 0.51 efg	156.40 ± 3.23 de	19.2 ± 0.58 ef
PK 10684-6-1-1	6.80 ± 0.58 bcdef	7.40 ± 0.68 def	163.00 ± 2.88 d	17.6 ± 0.51 fg
KSK 480	7.80 ± 0.37 bcd	7.80 ± 0.49 cde	167.80 ± 0.92 cd	15.2 ± 0.37 g
PK 9966-10-1	7.40 ± 0.68 bcde	8.60 ± 0.24 bcd	178.00 ± 0.84 bc	14.6 ± 0.51 g
PK 10355-13-2-1	7.80 ± 0.20 bcd	8.40 ± 0.24 bcd	183.60 ± 2.64 b	14.4 ± 0.81 g
PK 10683-12-1	8.40 ± 0.24 bc	9.40 ± 0.24 bc	182.80 ± 2.40 b	14.6 ± 0.93 g
KSK 476	8.80 ± 0.20 b	9.80 ± 0.20 b	188.20 ± 0.92 b	14.6 ± 0.93 g
TN (1)	12.00 ± 0.55 a	12.00 ± 0.63 a	237.00 ± 3.39 a	7.04 ± 0.54 h
HSD(P<0.01)	2.3	1.89	12.46	3.79
F-Value	17.17	32.86	167.09	81.23

Table I. Reaction of rice genotypes (Antixenosis) (Mean ± SE) to *Sogatella furcifera.*
Means with different lower-case letters within a column are significantly different at p ≤ 0.05 (Tukey's HSD test).

RESULTS

Antixenosis studies

Settling behavior of nymphs

Settling behavior of nymphs after release differs significantly among different rice genotypes ($F_{14, 74}$ = 17.17, P < 0.01). Among 15 different selected genotypes, a smaller number of nymphs were settled on rice genotypes RPP 49 (3.80) followed by Super Basmati, Basmati Pak, N22 and IR 72. Maximum number of nymphs were settled on TN1 (12) followed by KSK 476 and PK 10683 (Table I).

Settling behavior of adults

Settling behavior of adult *S. furcifera* after release was significantly different among different rice genotypes ($F_{14, 74}$ = 32.86, P < 0.01). Maximum number of adults (12) were settled on TN1 followed by KSK

476, PK 10683 and PK 9966 (Table I). Minimum number (4.40) of adults were settled on RPP 49 followed by N22, Basmati Pak, IR 64 and Super Basmati.

Fecundity

Fecundity differs significantly among different genotypes ($F_{14, 74}$ = 167.09, P < 0.01). It was significantly lower on RPP 49 (112) followed by N22, IR64, Basmati Pak, IR 72 and PKBB 8 (Table I). Maximum egg laying (237) was recorded on TN1.

Feeding marks

Number of feeding marks produced by *S. furcifera* was significantly different among different rice genotypes ($F_{14, 74}$ = 81.23, P < 0.01). Maximum feeding marks were recorded on RPP 49, followed by N22, IR 64, IR 72 and Basmati Pak, however Lowest number of feeding marks were recorded on TN1 followed by PK 10683 and KSK 476 (Table I).

Genotypes	Nymphal survival (%)	Feeding rate (mm^2)
RPP49	62 ± 3.74 e	47.8 ± 2.13 (1.67) i
N22	66 ± 5.10 de	51.6 ± 1.08 (1.71) hi
IR 64	68 ± 3.74 cde	54.8 ± 1.24 (1.74) gh
IR 72	70 ± 3.16 abcd	61.4 ± 1.08 (1.79) defg
Bas Pak (6129)	76 ± 5.10 bcde	56.6 ± 1.21 (1.75) fgh
Super Basmati	74 ± 6.00 bcde	57.8 ± 1.98 (1.76) efgh
PKBB 8	78 ± 4.47 abcd	62.2 ± 2.35 (1.79) def
PK 10436-4-2-2-1	84 ± 2.45 abc	62.6 ± 1.50 (1.80) def
PK 10684-6-1-1	86 ± 2.45 ab	60.8 ± 1.96 (1.78) defg
KSK 480	88 ± 3.74 ab	65 ± 0.71 (1.81) de
PK 9966-10-1	90 ± 3.16 ab	68.4 ± 0.51 (1.84) cd
PK 10355-13-2-1	84 ± 2.45 abc	65.2 ± 0.86 (1.81) d
PK 10683-12-1	90 ± 3.16 ab	73.8 ± 1.28 (1.87) bc
KSK 476	94 ± 4.00 a	78 ± 1.05 (1.89) b
TN (1)	96 ± 2.45 a	470.8 ± 6.52 (2.67) a
HSD (P<0.01)	17.82	3.79 (0.05)
F-Value	8.35	2452.21 (499.43)

Table II. Nymphal survival and feeding rate (Mean ± SE) of *Sogatella furcifera* on rice genotypes

Means with different lower-case letters within a column are significantly different at p ≤ 0.05 (Tukey's HSD test). Values in parenthesis are log10 transformed.

Genotypes	Adult emergence (%)	Developmental period (D)	Growth index
RPP49	85.6 ± 1.21 ef	14.08 ± 0.11 a	6.08 ± 0.10 (0.78) f
N22	87.4 ± 0.93 def	12.46 ± 0.18 b	7.02 ± 0.07 (0.85) e
IR 64	90.6 ± 0.51 bcd	11.8 ± 0.37 bcd	7.71 ± 0.27 (0.89) cde
IR 72	89.4 ± 0.51 cde	11.8 ± 0.20 bcd	7.58 ± 0.11 (0.88) cde
Bas Pak (6129)	83.6 ± 0.93 f	12 ± 0.32 bc	6.99 ± 0.25 (0.84) ef
Super Basmati	82.8 ± 0.73 f	12 ± 0.00 bc	6.90 ± 0.06 (0.84) ef
PKBB 8	84.2 ± 0.80 f	11.66 ± 0.42 bcde	7.27 ± 0.33 (0.86) de
PK 10436-4-2-2-1	90.4 ± 0.93 bcde	11 ± 0.00 cdef	8.22 ± 0.08 (0.91) bcd
PK 10684-6-1-1	90.8 ± 1.24 bcd	10.6 ± 0.24 def	8.59 ± 0.31 (0.93) abc
KSK 480	91 ± 0.89 bcd	10.8 ± 0.20 cdef	8.44 ± 0.24 (0.92) bc
PK 9966-10-1	92.2 ± 0.66 abcd	10.4 ± 0.24 ef	8.88 ± 0.16 (0.95) ab
PK 10355-13-2-1	94 ± 0.71 abc	10.6 ± 0.24 def	8.89 ± 0.20 (0.95) ab
PK 10683-12-1	94.4 ± 0.51 ab	10.6 ± 0.24 def	8.93 ± 0.25 (0.95) ab
KSK 476	93.2 ± 2.15 abc	10.4 ± 0.24 ef	8.98 ± 0.26 (0.95) ab
TN (1)	97 ± 0.71 a	10 ± 0.32 f	9.74 ± 0.35 (0.99) a
HSD (P<0.01)	4.89	1.26	1.1585 (0.06)
F-Value	19.1	17.77	19.62 (22.13)

Table III. Adult emergence, developmental period and growth index of *Sogatella furcifera* on different rice genotypes.
Means with different lower-case letters within a column are significantly different at p ≤ 0.05 (Tukey's HSD test). Values in parenthesis are log10 transformed.

Antibiosis studies

Nymphal survival

Nymphal survival rate was significantly different among rice genotypes ($F_{14, 74}$ = 8.35, P < 0.01). Minimum survival rate (62%) was recorded on RPP 49 followed by N22, IR 64, Super Basmati and Basmati Pak. Maximum survival rate (96%) was recorded on TN1 followed by KSK 476, PK 9966 and PK 10683 (Table II).

Feeding rate

Feeding rate varied among different rice genotypes ($F_{14, 74}$ = 2452.21, P < 0.01). Maximum feeding (470.8 mm^2) was observed on genotype TN1, followed by KSK 476, PK 10683, PK 9966 and KSK 480. Minimum feeding rate (47.8 mm^2) was recorded on RPP49 followed by N22, IR64, Bas Pak, Super Basmati, IR 72, PKBB 8, PK 10684 and PK 10436 rice genotypes (Table II).

Egg hatchability

Egg hatchability was inhibited on all the test varieties ($F_{14, 74}$ = 393, P < 0.01). There were no significant differences observed among all tested rice genotypes for egg hatchability except RPP49 (Fig. 2). On RPP49 egg hatchability was recorded (88.8%) and on TN1 was (97.32%).

Population growth rate

Population growth rate was significantly different among different rice genotypes ($F_{14, 74}$ = 400.90, P < 0.01). Maximum growth (598.2) was recorded on TN1, followed by PK 10683, PK 476 and PK 10355. Minimum growth rate (278.8) was observed on RPP49 followed by N22, Basmati Pak, Super Basmati and IR 64 (Fig. 3).

Adult emergence

Adult emergence of *S. furcifera* varied significantly among different rice genotypes ($F_{14, 74} = 19.1$, $P < 0.01$). Lowest emergence (82.8%) was recorded on Super Basmati rice variety while highest (97%) on TN1 (Table III).

Developmental period

Developmental period varied significantly among different rice genotypes ($F_{14, 74} = 17.77$, $P < 0.01$). Lowest developmental period (10 days) was recorded on TN1, followed by PK 10683, KSK 476 and PK 10355, respectively. Highest developmental period (14.08 days) was recorded on RPP49 followed by N22, IR 64, Super Basmati, Bas Pak and IR 72 rice genotypes (Table III).

Growth index

Growth Index varied significantly among different rice genotypes ($F_{14, 74} = 19.62$, $P < 0.01$). Highest growth index 9.74 was observed on TN1 and lowest growth index 6.08 observed on RPP49. Growth index was statistically at par in rice varieties PK 10436, PK 10684, KSK 480, PK 9966, PK 10355, PK 10683 and KSK 476 (Table III).

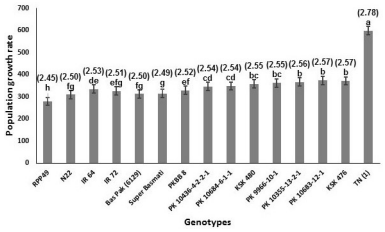

Fig. 3. Population growth rate of S. furcifera in different rice genotypes.
Means with different lower-case letters in each bar are significantly different at p ≤ 0.05 (Tukey's HSD test). Values in parenthesis are log10 transformed.

DISCUSSION

Host plant resistance is a key component in pest management programs due to its specificity to the target pests with no adverse effect on non-target organisms. Due to the migratory nature of *S. furcifera,* spray control decisions are difficult in a cropping season. Due to the increased insecticide resistance on *S. furcifera,* host plant resistance and development of resistant varieties is imperative. In monogenic rice lines only limited available resistant genes are effective. Hence, thorough screening of resistance in rice germplasms is essential for the detection and deployment of resistant genes against plant hoppers (Horgan et al., 2015).

Nymphs settled on the preferred rice genotypes after infestation. TN1 attracted most of the nymphs and adult population. After 24 hours most of the nymphs and adults were settled on different genotypes. About four times more nymphs and adults settled on the susceptible genotypes than the resistant ones. The scattered nymphs after a period of time locate the preferred varieties. The nymphs were attracted to different varieties due to visual or olfactory responses, but they did not settle on some varieties unless they fed. This is an important feature in the preference and non-preference of hoppers to the rice varieties (Pablo, 1977; IRRI,

1977). Higher number of *N. lugens* settled on susceptible genotypes as compared to resistant ones (Samal & Misra, 1990; Qiu et al., 2012; He et al., 2013). The same results were obtained in the case of *S. furcifera* (Shukla, 1984; Bhattal, 1992; Ramesh et al., 2014). In some experiments in which steam distillation extracts of resistant plants were sprayed on the susceptible ones, the results indicate the role of surface waxes and volatile compounds in insect's preference towards susceptible rice plants (Horgan, 2009). Our results were supported by Alagar & Suresh (2007) who revealed that the settling response of nymphs was more prominent after 24 hours of infestation. Average number of nymphs was lower on RPP49 (3.80 *per* plant) than the control TN1 (12 *per* plant). Highest egg lying was observed on TN1 (237) while lowest on RPP49 (112). Feeding behavior of the plant hoppers varied from variety to variety and this determined the food intake of the hoppers. Feeding includes probing *i.e*., use of proboscis and insertion of stylets into the plant tissues and the time of feeding. In our experiment, we observed more restive behavior of *S. furcifera* on RPP49, N22, IR 64 and IR 72 as the insect moved on all over the leaf sheath for probing to feed. These variations are due to the genetics of different genotypes (Heinrichs & Rapusas, 1983; Shukla, 1984; Gunathilagaraj & Chelliah, 1985; Bhattal, 1992; Du et al., 2009). N22 genotype with one resistant gene against *S. furcifera* also reported by Myint et al. (2009) in his study. Among the selected genotypes Basmati Pak (6129) was also documented as a resistant cultivar to whitebacked planthopper (Heinrichs et al., 1985). Results of the current study were supported by Bhattal (1992) who found that *S. furcifera* makes higher number of probes on ARC 11367, NCS 2041 and PR 109 than on TN1. These findings were further validated with electropenetrogram studies (Ghaffar et al., 2011).

Plant resistance is classified as antixenosis, antibiosis and tolerance. Laboratory bioassays are necessary for the evaluation of resistant varieties for resistance. Several no choice tests were performed like nymphal survival, adult longevity, honey dew measurement, egg hatchability and growth index on selected genotypes. Survival of the *S. furcifera* was lowest on RPP49, N22, IR 64 and IR 72, Basmati Pak and Super Basmati rice varieties. Egg hatchability was similar in most of cases except RPP49. TN1 and KSK 476 and PK 10683 had lowest level of resistance in population growth rate test. Despite equal feeding differences in the population, growth rate and growth index on different rice varieties were the indication of the variation in nutritive values of plant sap ingested. Population growth rate test was very useful as this was influenced both by nutritive value, feeding rate, ovipositional rate and survival. It gives us good judgment of the response under field conditions but it does not tell us about the tolerance level which ultimately affects the crop yield.

Resistant varieties limit survival and feeding of the insects. The survival of the nymphs on resistant varieties ranged between 50 to 70% in comparison with nearly 100% survival on susceptible TN1. Pathak (1977) revealed that 99 to 100% survival of first instar nymph of *S. furcifera* was on TN1, however on resistant ARC 5762 it was 30 to 70%.

These findings corroborated our results, where survival of the nymphs was 96% on TN1 and 62% on resistant RPP49. Nymphal survival ranged between 20, 60 and 100 percent in resistant, moderately resistant and susceptible rice varieties, respectively (Choi et al., 1973). In a study, nymphal survival of *S. furcifera* was recorded from 18 to 40% and 52 to 62% on resistant and moderately resistant rice genotypes after 12 days. On 20th day after infestation it was recorded as 12 to 28% and 36 to 48%, while TN1 exhibited 92% nymphal survival on day 12 and 72% survival on 20th day after infestation (Lal, 1981). Significantly lower survival of nymphs was found on ARC 10239, ADR 52 and IR 2035-117-3 than on the susceptible TN1 after 12 days of exposure to *S. furcifera* (Heinrichs & Rapusas, 1983). Lal, (1988), Ramaraju et al. (1989) and Huang et al. (2019) stated that survival of the nymphs was lowest on resistant and moderately resistant varieties than on susceptible cultivars. In a no choice design, Han et al. (2018) found significantly reduced survival and prolonged developmental duration of *N. lugens* nymphs on BR4831 genotype than on TN1 which indicate that the genotype BR 4831 is resistant to *N. lugens* nymphs. Furthermore, they observed reduced egg hatching rates, fecundity, female weights, female ratios, and longevity on BR 4831 plants followed by C 602 and HF106 plants as compared with TN1. Ramesh et al. (2014) evaluated resistance in rice variety Saina sivappu against *S. furcifera*. Several phenotypic tests like standard seed box screening test (SSST), nymphal preference, honey dew measurement, nymphal survival and days to wilt were evaluated. Results of the experiment revealed significant differences of resistance levels of variety Saina sivappu as compared to susceptible TN1. These results support our findings of reduced nymphal survival, feeding rate, growth index and longevity of *S. furcifera* on resistant rice varieties.

Differences in resistance levels among different genotypes with different resistant genes is very clear. This difference may not be due to major genes alone. Some minor resistant genes may also be involved. So, there will be greater differences among resistant varieties with major genes due to minor genes. Studies should be initiated to explore the effect of minor genes in resistant mechanism in the genotypes with major genes. It is concluded that the existing rice germplasm possesses resistance against white backed plant hopper. RPP49 is the new resistant variety to WBPH. N22, IR 64 and IR 72 have also shown resistance to *S. furcifera*. Basmati Pak (6129) and Super Basmati are moderately resistant while PKBB 8, PK 10684 and PK 10436 are new moderately resistant genotypes against WBPH. These genotypes can be used as resistance source in future breeding programs against WBPH. This will further contribute in the IPM programs against this insect pest, will be more environment friendly and will reduce chemical pressure on rice. As a result, the problem of insecticide residues in rice grains can be solved.

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