RICE IS CULTIVATED under diverse climatic, hydrological, and edaphic conditions. The stability of rice production frequently is threatened by increases in pest incidence and the prevalence of physicochemical stresses, including salinity. Several species of insects affect the rice crop in South and Southeast Asia. Of these, the whitebacked planthopper, S. furcifera, is a major pest in Fiji, Japan, Korea, Vietnam, Thailand, India, and Pakistan (Khan and Saxena, 1986a). Under favorable conditions, the insect produces several generations per crop and inflicts heavy damage due to hopperburn (Pathak, 1968).

In South and Southeast Asia, nearly 60 million ha of land are affected by salinity ranging from 0.4 to 1.8 S/m (Akbar, 1986). Higher levels of salinity are a major obstacle to high-grain yields on about 27 million ha of land in deltas, estuaries, and coastal fringes in Asia. These areas are physiographically and climatically suited to rice production, but grain yield is reduced drastically at salinity level of 1.0 S/m. High-yielding, semidwarf cultivars, which lack tolerance to salinity, are grown in inland saline areas, but low-yielding, salt-tolerant, traditional, tall 'indica'rices with long growth duration are cultivated in coastal saline environments (Akbar, 1987).

Plants grown under physical stresses frequently become more susceptible to insects (Rhoades, 1983), but little is known about the effects of salinity stress on the magnitude and expression of resistance to insect pests in rice cultivars. We therefore investigated the influence of salinity on rice plants and how it affected establishment of S. furcifera.

MATERIALS AND METHODS

Cultivars Tested

Rice cultivars IR2035, 'Non Bokra', 'Pokkali', and TN1 were selected for investigating the influence of salinity-induced changes in rice plants on the behavior and biology of S. furcifera. The cultivar IR2035, an improved line resistant to the planthopper, is highly sensitive to salinity. Nona Bokra and Pokkali; traditional, tall, salt-tolerant cultivars of coastal saline areas of India; are susceptible to the pest. TN1 is highly susceptible to the pest and sensitive to salinity.

Plant Culture

Seed was surface sterilized with 1 g/kg HgCl solution for 2 min, washed, soaked in water for 24 h, and then incubated at 30 °C for 48 h in petri dishes lined with moist filter paper. Pregerminted seeds were sown singly in holes (15-mm diam.) in culture foam plastic sheets with nylon-net bottoms that rested on 12-L plastic trays filled with the standard culture solution (Yoshida et al., 1976). Each culture foam plastic sheet (320 by 270 by 13 mm) had 30 holes bored equidistantly in six rows and was glued with epoxy on the lower side of a foam plastic frame (50-mm wide, 20-mm thick) along its inner border. The emerging seedlings were grown for 2 wk in the culture solution, the level of which was kept in contact with seedling roots. The pH of the culture solution was adjusted daily to 5 using either 1 M NaOH or 1 M HCl. The culture solution was changed at weekly intervals. The seedlings were subjected to salinization by adding NaCl and CaCl2 (1:1 by weight) to the culture solution to get the desired salinity levels of 1.0 or 1.2 S/m, using an electrical conductivity meter. Control plants were grown in the standard culture solution. Salinization continued for 35 to 75 d, depending on the duration of the experiment. Data were recorded for plant height, root length, and biomass of rice plants.

Steam Distillation and Extraction of Rice Plants for Allelochemicals

Leaf sheaths of 20 rice plants grown in salinized or standard culture solution for 40 d were harvested and coarsely ground with an electric grinder. Following the distillation and extraction procedure of Saxena and Okech (1985), a 200-g sample was steam distilled for 4 h, during which ca. 900 mL of distillate was collected. The distillate was extracted with diethyl ether (300 mL distillate : 100 mL diethyl ether) by shaking a mixture of the two together in a separatory funnel for 5 min. Diethyl ether absorbed essential oils and other volatiles and the mixture settled above the water layer in the funnel. The water layer was discarded. The ether extract was pooled in a glass beaker, to which 100 g of an-
g/L concentration.

The extract was evaporated further to 10 mL and decanted covered with aluminum foil and held overnight to allow the hydrous sodium sulfate was added. The beaker was then soaked for 24 h in 25 mL 1M HCl and then filtered with a 10-mL mixture of HClO4:HNO3:H2SO₄ (300:750:150 mL) on a hot plate and 500 °C until a gelatinous white residue was obtained. The mixture was filtered through Whatman filter paper was burned at 500 °C for 4 to 5 h for gravimetric determination of crude Si.

Elmet, Model 2380, Norwalk, CT). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY). The residue on the filter was dissolved in 2 mL of concentrated nitric acid and 1 mL of 2% aqueous Se:K2SO4, 1 mL of 10% HCl, and 1 mL of 0.1% K tartrate and heat was applied until the solution was clear. The solution was evaporated to dryness on a hot plate and cooled, and then 3 mL of 10% HCl was added and evaporated to dryness. The residue was extracted with 2 mL of 10% HCl and 3 mL of 30% HNO3 and allowed to stand overnight. The mixture was filtered, and the filtrate was brought to 100 mL with deionized distilled water. Nitrogen was determined colorimetrically as indophenol blue on an auto-analyzer (Technicon Instrument Corp., Tarrytown, NY).
ranged in a randomized complete-block design. There were four replicates for each treatment. The pH of the culture solution was adjusted daily to 5.5. Growth was measured by the number of nymphs that became adults and the time taken to reach the adult stage. The insect-growth index on stressed and unstressed plants was calculated as the ratio of percentage nymphs becoming adults to the mean growth period in days (Saxena et al., 1974).

Adult Longevity and Fecundity

Plants stressed for 35 d and kept in salinized culture solution and unstressed plants kept in standard culture solution in plastic pots were infested with 10 pairs of newly emerged females (brachypterous) and males and covered with Mylar-film cages, as described above. The infested plants were arranged in a randomized complete-block design and each treatment was replicated four times. Insect mortality was registered daily until all individuals died. The total number of nymphs emerged on each plant was recorded and represented the number of viable eggs laid by the females. At the end of the nymphal emergence, unhatched eggs also were counted by dissecting leaf sheaths under a 20× binocular microscope. The total number of nymphs emerged and the number of unhatched eggs represented the fecundity of S. furcifera females.

Population Increase

Salinity-stressed and control plants grown in salinized and standard culture solution, respectively, at four plants per pot (180-mm deep, 160-mm diam.) were infested with five pairs of newly emerged females (brachypterous) and males using Mylar cages (1000-mm high, 170-mm diam.), as described above. The infested plants were arranged in a randomized complete-block design and each treatment was replicated four times. Insects, both nymphs and adults, were counted 40 d after infestation.

Data for tests on food intake and assimilation, growth, adult longevity and fecundity, and population increase were subjected to analysis of variance and the means were compared using Duncan's (1951) multiple range test at the P < 0.05 and the least significant difference test at P < 0.05 and 0.01 levels (Gomcz and Gomez, 1984).

RESULTS

Salinity Effects on Rice Cultivars

Salinity significantly reduced plant height, root length, and biomass in all cultivars (Table 1). The reduction in growth parameters was greater in the salt-sensitive cultivar IR2035 than in salt-tolerant cultivars Nona Bokra and Pokkali. Salinization also influenced the chemical composition of rice plants (Table 2). Nitrogen, Ca, and Fe increased, while K content decreased at electrical conductivity of 1.2 S/m in the leaf sheath. Both salinity levels decreased the quantity of allelochemicals recovered as steam-distillate extracts from all cultivars (Table 3), but the reduction was greater at 1.2 than 1.0 S/m. The reduction in the quantity of allelochemicals produced was greater in salt-sensitive IR2035 than in salt-tolerant cultivars Nona Bokra and Pokkali.

Effect on Insect Responses

Orientational Response

Salinity stress did not alter plant attractiveness to S. furcifera females. However, application of steam-distillate extract from salinity-stressed or unstressed insect-resistant IR2035 plants to susceptible TN1 plants rendered them less attractive to the insect. Chi-square values were significant for deviations from means of total times the females alighted on nylon.
and 16.8\(^\circ\)C).

Significant at P = 0.05 and 0.01 at 1.0 and 1.2 S/m,

with extract of stressed (x 2 = 14.4\(^2\) and 31.7\(^2\) [significant walls facing control TN1 plants and plants treated

Taichung

Table 3. Effect of salinity stress on production of allelochemicals by

S. furcifera

nymphal growth and development increased significantly on all test eultivars at 1.2 S/m but not at 1.0

Pokkali 0.54b 0.52b 0.02NS 0.38b 0.35b 0.03NS

Nona Bokra 0.51b 0.50b 0.0NS 0.39b 0.34b 0.05*

IR2035-117-3 0.18c 0.14c 0.04NS 0.17c 0.12c 0.05*

Native I 0.62a 0.59a 0.03NS 0.56a 0.51a 0.05*

Pokkali 9.1b 9.0b 0.1NS ll.7b 8.9b 2.8*

Nona Bokra 9.8b 9.3b 0.5NS 10.5b 8.2b 2.3*

IR2035-117-3 5.3c 3.9c 1.4NS 4.4c 3.2c 1.2NS

Table 4. Intake and assimilation of food by

Pokkali 43.0 47.5 9.47 37.25 45.75 18.58

Nona Bokra 42.0 45.5 7.69 35.7 45 20.67

IR203-117-3 52.5 62.5 16.00 45.75 63.75 28.24

S. furcifera

Decrease Decrease

over over

Food assimilated, \(\text{mg/female/24 h}\)

Food intake, \(\text{mg/female/24 h}\)

IR2035 but assimilation of food increased signifi-

Pokkali at 1.2 S/m, but assimilation of food was

TN1 and Nona Bokra plants. Food intake increased

sect's intake and assimilation of food (Table 4), but

Regardless of salinity level, intake and assim-

values followed by the same letter in each column are not significantly

Native I 1 0.62a 0.58a 0.04NS 0.21a 0.18a 0.03NS

Pokkali 5.14b 4.79b 0.35NS 5.35b 4.59b 0.76**

Nona Bokra 5.28b 4.93b 0.35NS 5.09b 4.31b 0.78**

IR2035-117-3 2.34c 1.60c 0.74** 2.32c 1.71c 0.61**

Taichung

Table 5. Intake and assimilation of food by

Pokkali 80.0b 75.0b 5.0NS 85.0b 75.0b 10.0*

Nona Bokra 82.5b 77.5b 5.0NS 80.0b 70.0b 10.0*

IR2035-117-3 42.5c 30.0c 12.5** 42.5c 32.5c 10.0*

Native I 1 17.9a 16.4a 1.5NS 6.4a 5.7a 0.7NS

Pokkali 15.6b 15.7b -0.1NS 15.9b 16.3b -0.4*

Nona Bokra 15.6b 15.7b --0.1NS 15.7b 16.3b -0.6*

IR2035 18.2a 18.9a -0.7** 18.4a 19.1a -0.7**

Taichung

Table 6. Growth and development of

Pokkali 0.53b 0.49bc 0.04NS 0.17ab 0.18a -0.0INS

Nona Bokra 0.54ab 0.50ab 0.04NS 0.19ab 0.17ab 0.02NS

IR2035-117-3 0.49b 0.41c 0.08* 0.14b 0.11b 0.03NS

NS,*,** ffi Nonsignificant and significant at the 0.05 and 0.01 probability

Values followed by the same letter in each column ate not significantly

respectively, by the least significant difference test.

Analysis is based on values transformed to arcsin \(\sqrt(X)\) for percent

first-instat nymphs becoming adults.

Growth index ffi percent nymphs becoming adults divided by mean devel-

mental period.

Insect population increased significantly on all cul-

trivars at salinity level of 1.2 S/m, but population in-

different at 0.05 probability level by Duncan's multiple range test.

Values followed by the same letter in each column ate not significantly

susceptible (S) Taichnng Native 1 and resistant (R) IR2035 plants

steam-distillate extract in acetone at 0.2 mL/tiller.
Salinity stress is known to increase or decrease the mineral content in rice plants. Salinity stress increased mineral content in rice plants. Salinity stress increased or decreased the production of plants (Levitt, 1972; Harborne, 1977). Furthermore, deficiencies of K enhance population build-up of phytophagous insects. Allelochemicals also determine the insect interactions (Whittaker and Feeney, 1971). A1-allochemicals produced by rice cultivars are susceptible to herbivores. The relationships between phytophagous insects and their plant hosts are subtle and intimate, and are affected by salinity stress (Murty and Rao, 1975). Salinity decreased starch and cellulose content. There were no significant differences in nutrient content other than P content (Hinckley, 1963; Fennah, 1971; White, 1976). Also, stresses weaken the plant and survive. Increase in N was 56% in the salinity-stressed plants compared with 30% in Nona Bokra, 31% in TN1, and 35% in Pokkali. Likewise, K content decreased more in IR2035 than in Nona Bokra. Increase in N content in rice plants enhanced growth and development, male and female longevity, and survives. Increase in N was 56% in the salinity-stressed plants compared with 30% in Nona Bokra, 31% in TN1, and 35% in Pokkali. Likewise, K content decreased more in IR2035 than in Nona Bokra. Increase in N content in rice plants enhanced growth and development, male and female longevity, and survives. Increase in N was 56% in the salinity-stressed plants compared with 30% in Nona Bokra, 31% in TN1, and 35% in Pokkali. Likewise, K content decreased more in IR2035 than in Nona Bokra. Increase in N content in rice plants enhanced growth and development, male and female longevity, and survives.
The present study also showed that salinity stress reduced the quantitative production of allelochemicals in all cultivars, but reduction was of greater magnitude in the insect-resistant and salinity-sensitive cultivar IR2035. The effect of allelochemicals on insect responses was similar whether allelochemicals were extracted from salinity-stressed or unstressed plants. An increase in salinity decreased the production of allelochemicals in plants, but did not alter their nature or quality. Thus, application of allelochemicals from insect-resistant IR2035 plants to susceptible TN1 plants made them less attractive and reduced the insect's food intake on them. This study also demonstrated that IR2035 plants possess allomones or defence chemicals against *S. furcifera*. It should be useful to identify these resistance-imparting chemicals in rice plants. Studies on their inheritance will pave the way for successful transfer of such traits to improved plant types.

The present study showed that salinity-induced changes in rice plants increased their susceptibility to *S. furcifera*. Therefore, the effects of salinity stress on the suitability of plants must be taken into consideration when breeding rice cultivars for saline areas.

ACKNOWLEDGMENTS

Muhammad Salim is grateful to the Pakistan Agricultural Research Council and the International Rice Research Institute for the scholarship which enabled him to pursue this work. He also thanks B.S. Vergara for providing the necessary facilities for this study. Assistance of the staff of the Analytical Services Laboratories in analyzing plant samples is appreciated.