Factors Contributing to Resistance in Rice to the Rice Water Weevil, Lissorhoptrus Oryzophilus Kuschel.

Francois Kouame N’guessan

Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Recommended Citation
https://digitalcommons.lsu.edu/gradschool_disstheses/5536

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road. Ann Arbor, MI 48106-1346 USA
313/761-4700  800/521-0600
Factors contributing to resistance in rice to the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel

N’Guessan, Francois Kouame, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1993
FACTORS CONTRIBUTING TO RESISTANCE IN RICE TO THE RICE WATER WEEVIL, LISSORHOPTRUS ORYZOPHILUS KUSCHEL

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirement for the degree of Doctor of Philosophy

in

The Department of Entomology

by

Francois K. N'Guessan
B.S., University of Abidjan, 1985
M.S., University of Georgia, 1989
May 1993
I am very thankful to the Ministry of Scientific Research of the Côte d'Ivoire government and the Department of Entomology, Louisiana State University for their financial support. If there is any scientific merit in this study, it is due to the expert guidance and encouragement of my Major Professor, Dr. Sharron S. Quisenberry. I endlessly thank her for her kindness and willingness to help.

I wish to express my appreciation to my committee members (Drs. Jerry B. Graves, Frank S. Guillot, Thomas J. Riley, and Richard N. Story) for their assistance in my research program and their constructive remarks and suggestions to the manuscripts. I express my gratitude to the employees and technicians of the Entomology Laboratory of the Rice Research Station, Crowley, La., for their assistance with the field exercises. I wish to extend my appreciation to the students and associates in the Rice and Forage laboratory for their suggestions.

I also wish to thank my family and all my friends in Côte d'Ivoire and in the United States for their encouragement and moral support. Special thanks goes to my older brother Mr. Bernard K. N'Guessan, my wife Carmen J. Lyttle-N'Guessan and my son Jean-Ponce K. N'Guessan, who stood by me and supported me throughout this study.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>xi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>CHAPTER I ASSESSMENT OF LOUISIANA RICE BREEDING LINES FOR TOLERANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)</td>
<td>26</td>
</tr>
<tr>
<td>Introduction</td>
<td>27</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>29</td>
</tr>
<tr>
<td>Results</td>
<td>31</td>
</tr>
<tr>
<td>Discussion</td>
<td>45</td>
</tr>
<tr>
<td>References - Chapter I</td>
<td>48</td>
</tr>
<tr>
<td>CHAPTER II EVALUATION OF RICE TISSUE CULTURE LINES FOR RESISTANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)</td>
<td>51</td>
</tr>
<tr>
<td>Introduction</td>
<td>52</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>54</td>
</tr>
<tr>
<td>Results</td>
<td>59</td>
</tr>
<tr>
<td>Discussion</td>
<td>84</td>
</tr>
<tr>
<td>References - Chapter II</td>
<td>89</td>
</tr>
<tr>
<td>CHAPTER III SCREENING SELECTED RICE LINES FOR RESISTANCE TO RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)</td>
<td>93</td>
</tr>
<tr>
<td>Introduction</td>
<td>94</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>96</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>100</td>
</tr>
<tr>
<td>References - Chapter III</td>
<td>126</td>
</tr>
<tr>
<td>CHAPTER IV EVALUATION OF RICE ANther CULTURE LINES FOR TOLERANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)</td>
<td>130</td>
</tr>
<tr>
<td>Introduction</td>
<td>131</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>132</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>135</td>
</tr>
<tr>
<td>References - Chapter IV</td>
<td>155</td>
</tr>
<tr>
<td><strong>CHAPTER V</strong></td>
<td></td>
</tr>
<tr>
<td>INVESTIGATION OF RICE ANTI-XENOSIS AND ANTI-BIOSIS TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)</td>
<td>158</td>
</tr>
<tr>
<td>Introduction</td>
<td>159</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>160</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>161</td>
</tr>
<tr>
<td>References - Chapter V</td>
<td>169</td>
</tr>
<tr>
<td><strong>SUMMARY AND CONCLUSIONS</strong></td>
<td>171</td>
</tr>
<tr>
<td><strong>BIBLIOGRAPHY</strong></td>
<td>174</td>
</tr>
<tr>
<td><strong>VITA</strong></td>
<td>183</td>
</tr>
<tr>
<td>TABLE</td>
<td>Description</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td>1.1</td>
<td>Mean number of rice water weevil larvae in Louisiana breeding lines evaluated for tolerance, Crowley La. 1991-1992</td>
</tr>
<tr>
<td>1.2</td>
<td>Height and yield of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991</td>
</tr>
<tr>
<td>1.3</td>
<td>Height and yield of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992</td>
</tr>
<tr>
<td>2.1</td>
<td>Mean number of rice water weevil larvae per core in rice tissue culture lines evaluated for tolerance, Crowley La. 1991-1992</td>
</tr>
<tr>
<td>2.2</td>
<td>Mean height and percent height difference of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991-1992</td>
</tr>
<tr>
<td>3.1</td>
<td>Mean number of rice water weevil larvae per core and yield of selected rice lines evaluated for tolerance, Crowley La., 1991</td>
</tr>
<tr>
<td>3.2</td>
<td>Mean number of rice water weevil larvae per core in selected rice lines evaluated for tolerance, Crowley La., 1992 (Trials 1 and 2)</td>
</tr>
<tr>
<td>3.3</td>
<td>Height and yield of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 (Trial 1)</td>
</tr>
<tr>
<td>3.4</td>
<td>Height and yield of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 (Trial 2)</td>
</tr>
<tr>
<td>3.5</td>
<td>Mean number of rice water weevil larvae per core in selected rice lines evaluated for antixenosis/antibiosis, Crowley La., 1991-1992</td>
</tr>
<tr>
<td>4.1</td>
<td>Mean number of rice water weevil larvae per core in rice anther culture lines evaluated for tolerance, Crowley La. 1991-1992</td>
</tr>
</tbody>
</table>
4.2 Height and yield of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991 .............. 146

4.3 Height and yield of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 .............. 147

5.1 Mean number of rice water weevil larvae per pot in selected Louisiana Breeding lines evaluated for antixenosis/antibiosis, Crowley La., 1991-1992 ......................... 162
<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991</td>
<td>34</td>
</tr>
<tr>
<td>1.2</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992</td>
<td>36</td>
</tr>
<tr>
<td>1.3</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991</td>
<td>38</td>
</tr>
<tr>
<td>1.4</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992</td>
<td>40</td>
</tr>
<tr>
<td>2.1</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991</td>
<td>63</td>
</tr>
<tr>
<td>2.2</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992</td>
<td>65</td>
</tr>
<tr>
<td>2.3</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991</td>
<td>67</td>
</tr>
<tr>
<td>2.4</td>
<td>Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992</td>
<td>69</td>
</tr>
</tbody>
</table>
2.5 Yield of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991 ........................................ 71

2.6 Yield of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 ........................................ 73

2.7 Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1991 .......................... 76

2.8 Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992 .......................... 78

2.9 Mean number of rice water weevil larvae and pupae per pot in rice tissue culture lines evaluated for resistance, Baton Rouge, La., 1991 (Greenhouse experiment) ....................... 80

2.10 Mean number of rice water weevil larvae and pupae per core in rice tissue culture lines evaluated for resistance, Crowley, La., 1992 (Field experiment) ....................... 82

3.1 Root damage ratings at 28 and 35 d postflood of plants in untreated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991 ...................... 104

3.2 Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 ...................... 106

3.3 Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 ...................... 108

3.4 Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of selected rice lines evaluated for resistance to the
3.5 Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of selected rice lines evaluated for resistance to the rice water weevil, Crowley, La., 1992 (trial 2) ................................... 116

3.6 Rice water weevil larval populations in different size categories for selected rice lines evaluated for resistance, Crowley, La., 1991....................................................... 120

3.7 Rice water weevil larval populations in different size categories for selected rice lines evaluated for resistance, Crowley, La., 1992....................................................... 122

4.1 Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice anther culture lines evaluated for tolerance to the rice water water weevil, Crowley, La., 1991....................................................... 138

4.2 Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice anther culture lines evaluated for tolerance to the rice water water weevil, Crowley, La., 1992....................................................... 140

4.3 Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice anther culture lines evaluated for tolerance to the rice water water weevil, Crowley, La., 1991....................................................... 142

4.4 Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice anther culture lines evaluated for tolerance to the rice water water weevil, Crowley, La., 1992....................................................... 144

4.5 Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice anther culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1991....................................................... 149
Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice anther culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992........................ 151

Percentage of rice water weevil larval populations in different size categories for three Louisiana breeding lines exhibiting resistance, Baton Rouge, La. 1991................................. 164

Percentage of rice water weevil larval populations in different size categories for three Louisiana breeding lines exhibiting resistance, Baton Rouge, La. 1992................................. 166
ABSTRACT

Studies were conducted in the field and greenhouse to identify sources of rice water weevil (Lissorhoptrus oryzophilus Kuschel) resistance in rice, Oryza sativa L., and determine the mechanisms of resistance. Rice lines of various sources, including breeding lines, somaclone lines and world collection lines, were evaluated. Tolerance was investigated using replicated insecticide treated and untreated plots in a split-plot design, and antibiosis and/or antixenosis were assessed using caged insect-infested plants in randomized block designs. Resistance predictors included rice water weevil larval populations, larval root pruning damage, plant height and grain yield.

Anther culture lines 95-2836 and 95-3527, Louisiana breeding lines 8720906 and 8721937, tissue culture lines 112 and 4754, and five lines of various sources (AL6029, LA2218, TX22041, URN199, URN200) exhibited moderate tolerance to the rice water weevil. These lines did not have significant (P < 0.05) yield differences between treated and untreated plots, while supporting high larval populations in the untreated plots. Root damage rating data indicated that these lines are capable of recovering from root pruning damage. In addition, the lines exhibiting tolerance produced higher grain yields than the susceptible check Mars.

Antixenosis and/or antibiosis tests revealed that two tissue culture lines (244, 2232), three Louisiana breeding
lines (8723417, 8723518, 8825454) and two Texas lines (TX12685 and TX13079) sustained significantly ($P < 0.05$) lower rice water weevil larval populations than the susceptible check Mars. Assessment of the percentage of larval populations in different size categories (small [0-3 mm], medium [3-6 mm] and large [6-10 mm]) suggested that nonpreference for oviposition by the adult weevil may be the mechanism of resistance in these lines.
INTRODUCTION

Rice is one of the most important food crops of the world. About 90 percent of the world rice crop is grown and consumed in Asia. The United States produces only 1 percent of the world supply, but is the leading rice producing country in North America and only second to Brazil in the western hemisphere. In the United States, rice is primarily grown in Arkansas, California, Louisiana, Mississippi and Texas.

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most damaging rice insect pest in Louisiana as well as other rice growing areas of the United States. Adults feed on the leaves and the larvae feed on the roots. The principal means of control of the rice water weevil has been the application of insecticides directed against the larvae. Aldrin, dieldrin and lindane seed treatments gave effective larval control in the 1950's and early 1960's (Bowling 1967). This practice led to the development of resistant populations of weevils in Louisiana (Hendrick and Everett 1963, Graves et al. 1967), Arkansas (Rolston et al. 1965), and Texas (Bowling 1968). Granular carbofuran broadcast aerially 1 week after permanent flooding of rice has since been shown to provide effective control of resistant rice water weevil populations (Gifford and Trahan 1967, Gifford et al. 1969, 1970). Presently, carbofuran is the only insecticide registered for control of the rice
water weevil. However, carbofuran is being banned as of 1995 for use on rice due to adverse effects on birds (Heier 1991).

In an effort to find alternatives to chemical control, Isely and Schwartd (1934), Robinson et al. 1980), Morgan et al. (1989), and Hesler et al. (1992) found that draining rice fields provided effective control of rice water weevil larvae. However, these researchers suggested that early season drainage conflicts with other management practices such as fertilizer and herbicide applications, and it can increase cost of production. In Louisiana, field research was conducted during 1989 and 1990 to compare the impact of carbofuran usage and water management as rice water weevil control tactics on rice yields (Quisenberry et al. 1992). The results showed that drainage gave effective larval control and the water management treatments had higher yield and grain/straw ratio than the other treatments. The data indicated that water management has potential as a cost effective pest management tool for control of the rice water weevil.

Host plant resistance could prove to be a suitable alternative and an effective addition to other management tactics for control of the rice water weevil. Previous rice germplasm screening studies (Gifford and Trahan 1975, Grigarick et al. 1976) have revealed some lines with low to moderate resistance to the rice water weevil. Two world collection lines designated 'WC1711' and 'CI11048' were
identified by Grigarick et al. (1976) in California and three world collections lines (WC1403, WC1349, WC1815) were identified by Gifford and Trahan (1975) in Louisiana as having moderate tolerance to the rice water weevil. These lines have been used as "parents" in the breeding program at the Rice Research Station, Crowley, Louisiana.

The objectives of this study were to identify sources of rice water weevil resistance in rice germplasm for potential use in rice breeding programs and to determine the mechanisms of resistance. The research agenda included the following: the identification of the principle of host preference by the adult rice water weevil, the effect of the rice host on the biology of the rice water weevil, and the ability of a germplasm line to withstand and outgrow rice water weevil damage and minimize yield reduction.
References - Introduction

Bowling, C. C. 1967. Test with insecticides as seed treatments to control rice water weevil. J. Econ. Entomol. 60: 18-19.


Isely, D. and H. H. Schwardt. 1934. The rice water weevil. Arkansas Agricultural Experiment Station Bulletin 299.


LITERATURE REVIEW

Rice belongs to the family Graminae, tribe Oryzae, subtribe Oryzinae, and genus Oryza. There are two species of cultivated rice, Oryza sativa L. and Oryza glaberrima Steud. The former is the common rice species grown worldwide, and the latter is a species cultivated in parts of Africa. Besides these cultivated species, the genus Oryza is comprised of approximately 22 wild species (Roy 1985). Several researchers (Chang 1976, Lu and Chang 1980, Morishima 1984, Sampath 1985) have investigated the origin and distribution of rice throughout the world. There is strong archeological evidence that O. sativa was domesticated in southern Asia, most probably in China, while O. glaberrima was domesticated in Africa (Lu and Chang 1980, Morishima 1984). Rice was dispersed to other regions and countries through migration or commercial routes. Lu and Chang (1980) stated that traders brought rice from tropical Asia and China to north Africa, Europe, Australia, and the Americas.

Rice cultivation was initially made in the United States as a trial planting in Virginia around 1609 (Lu and Chang 1980). Lu and Chang (1980) stated that rice production was well established in South Carolina around 1690 and production spread to southwest Louisiana, Texas and Central Arkansas. California began to produce rice between 1909 and 1912 (Lu and Chang 1980).
Estimation of worldwide rice production in 1978 indicated that approximately 144.7 million hectares of rice were grown in the world, producing 376.9 million tons of rice (Lu and Chang 1980). Asia accounts for about 90% of the world's rice hectarage (Lu and Chang 1980), with only 10% produced in the rest of the world. Rice is grown in Louisiana, Texas, Arkansas, Mississippi and California in the United States. These states account for only 0.85% of the world hectarage (Lu and Chang 1980).

Rice is primarily grown as food for human consumption. It is one of the most important cereal foods in the world. It provides a larger proportion of food than any other single crop and is the staple food of over half of the world's population. The nutritional value of rice is mostly provided by carbohydrates (75% to 80%) and proteins (4.5% to 14.5%) (Kennedy 1980). However, rice contains small amounts of other nutrients such as fat, fiber, calcium, phosphorus, iron, sodium, potassium, thiamin, riboflavin and niacin (Kennedy 1980).

The pest spectrum of rice is wide and practically every part of the plant has an adapted species during every stage of growth (Bowling 1980, Cogburn 1980). From the time of germination until the grain is ready for harvest, and even in postharvest storage, several pests are capable of inflicting serious damage to the plant or seed. Insects are the most important pests in rice culture, although other serious pests include pathogens, weeds, rodents, and
birds. Over 800 species of insects have been recognized as potentially damaging to rice (Grist and Lever 1969). However, the pest status of the different insect species vary from one country or region to another. Leafhoppers (Nephotettix virescens [Distant], Nephotettix centiceps Uhler, Nephotettix nigropictus [Stal]), planthoppers (Nilaparvata lugens [Stal], Sogatella furcifera Horvath, Laodelphax striatellus Fallen), stems borers (Chilo suppressalis Walker, C. zacconius Blesz), and the gall midge (Orseolia oryzae [Wood-Mason]) have been reported to be the most damaging insect pests in Asian and African countries (Panda 1979).

In the United States, important rice pests include the chinch bug (Blissus leucopterus Say), fall armyworm (Spodoptera frugiperda [J. E. Smith]), rice leafminer (Hydrellia griseola Fallen), sugar cane borer (Diatraea saccharalis Fabricius), rice stalk borer (Chilo plejadellus Zinken), grape colaspis (Colaspis flavida Say) and rice stink bug (Oebalus pugnax Fabricius) (Bowling 1967a). However, the rice water weevil (Lissorhoptrus oryzophilus Kuschel) is the most destructive insect pest of rice in Louisiana as well as other rice growing areas of the United States. The biology and behavior of the rice water weevil has been studied by Tucker (1912), Isely and Schwardt (1934), Bowling (1967a, 1972) and Cave and Smith (1983). The rice water weevil is native to North America and occurs in Canada, United States and Mexico (Kuschel 1951). This
insect is a threat to rice production in some Asian countries because it was accidently introduced in Japan, presumably in infested rice straw (Hirao 1978).

The rice water weevil was initially described by Say in 1831 as Bagous simplex (Tucker 1912). However, in 1876, this insect was placed in the genus Lissorhoptrus by Leconte (Isely and Schwardt 1934). Early researchers referred to this insect species as Lissorhoptrus simplex Leconte. Kuschel (1951) revised the genus Lissorhoptrus and gave the name oryzophilus to the species most commonly found in the southern United States. Bowling (1964) reported that both L. simplex and L. oryzophilus occurred in the southern United States, but the latter was the predominant species.

Adult rice water weevils are small, dark brown, oblong (2.8 mm long by 1.2-1.8 mm wide) with gray scales (Isely and Schwardt 1934). Normally, the adults are sexually dimorphic and undergo sexual reproduction. The abdomen of the female is more robust than that of the male. In the female, the first two ventral abdominal sternites are flat to convex at the midline whereas they are broadly concave in the male (Everett and Newsom 1964). Females have a large darkened area on the elytra and a deep notch in the seventh tergal segment, and are often larger than males (Smith 1983). The rice water weevil is parthenogenic in California (Lange and Grigarick 1959) and Japan (Hirao 1978).
The adults are semi-aquatic and spend much of their life either on or beneath the water surface. When disturbed on the plants, they fall into the water and dive beneath the surface to avoid capture (Smith 1983). The adults use several aquatic grasses and sedges in and around rice fields as alternate hosts for feeding and oviposition (Newell 1913, Webb 1914, Isely and Schwardt 1934 and Lange and Grigarick 1959).

The rice water weevil overwinters as an adult in a true diapause (Knabke 1973, Nilakhe 1977). Adult weevils leave the field and fly to hibernation sites as early as July to overwinter in bunch grasses (Grigarick and Beards 1965), Spanish moss (Tucker 1912), and ground trash (Newsom and Swanson 1962). The flight muscles of the overwintering weevils are reduced in size, but regenerate prior to spring immigration to flooded rice fields and degenerate when oviposition begins (Muda et al. 1981). Webb (1914) found that adult weevils emerge from hibernation sites between 25 March and 26 June in Louisiana.

The egg is white, elongate, about 0.8 mm long and three or four times as long as broad (Webb 1914, Ingram 1927). The larvae are white, legless grubs, morphologically distinctive due to the presence of paired dorsal tracheal hooks on the second through seventh abdominal segments (Isely and Schwardt 1930). There are four larval instars with head capsule widths varying in size from 0.16 mm to 4.5 mm (Cave and Smith 1983). The
pupa, which is formed in an oval, water-tight mud cell, resembles an adult in size and shape but is white in color (Isely and Schwartt 1934). Under normal field conditions the larval stages last approximately 27 days and the pupal stage last seven days (Smith 1983).

Both adult and larvae of the rice water weevil can cause damage to the rice plant. Adults feed on rice plants by rasping away the leaf epidermis, leaving skeletonized longitudinal slit-like scars. Adults feeding damage to the foliage is generally of little importance, although Ingram (1927) reported plant death due to adult feeding on seedlings in some late planted rice fields. However, damage caused by the larvae is more serious to the health of the rice plant and it is considered economically important (Newsom and Swanson 1962). Root pruning by the larvae stunts the growth of younger plants, and causes lodging and yield reduction in mature plants (Bowling 1967a, Smith 1983). Smith (1983) stated that in Louisiana average yield reductions are about 10% in rice crops not treated with insecticides. Other researchers (Tucker 1912, Bowling 1957, Rolston and Rouse 1960, Newsom and Swanson 1962, Grigarick 1963) have reported yield losses ranging from 1 to 75%. Control of the rice water weevil is necessary to prevent severe economic yield losses on rice in the rice growing areas of the United States.

Worldwide, the initial approach to rice insect control included the combination of mechanical methods such as
removal of egg masses and affected tillers with cultural methods such as trap crops, dates of planting and plowing of the field to bury the stubbles were used by some traditional farmers in India to reduce infestation by stem borers and the gall midge (Khan 1964, Rao and Kulshreshtha 1985). Control of rice borers by cultural practices (e.g., shifting transplanting dates, flooding fallow fields, hand removal of egg masses, and digging out or burning stubbles, in association with the use of light traps and conservation of egg parasites) was commonly used 100 years ago in Japan (Kiritani 1979). However, the most effective means of control for most rice insects have been the frequent applications of insecticides. Insecticides such as endrin, parathion, diazinon, carbaryl, granular carbofuran, phorate, monocrotophos, BHC, DDT, endosulfan and dieldrin have been effective in controlling a number of rice insect pests in Asia (Kiritani 1979, Rao and Kulshreshtha 1985).

In the United States, early insecticides used for rice water weevil control included dieldrin, lindane, aldrin, chlordane, DDT, heptachlor, toxaphene, and endosulfan (Bowling 1967b). Aldrin seed treatment was the most commonly used method for control of the rice water weevil in the early 1960's (Bowling 1967b). The rice water weevil became resistant to aldrin in Louisiana (Hendrick and Everett 1963, Graves et al. 1967), Arkansas (Rolston et al. 1965), and Texas (Bowling 1968). Granular carbofuran broadcast aerially 1 week after permanent flooding of rice
has been shown to give effective control of aldrin resistant rice water weevil populations (Gifford and Trahan 1967, Gifford et al. 1969, 1970). Presently, carbofuran is the only insecticide registered for control of the rice water weevil. Each year insecticides screening tests are conducted in an effort to identify alternate insecticides for use pending rice water weevil development of resistance to carbofuran (Robinson et al. 1983, 1985, 1986; Quisenberry et al. 1990a, 1990b). In addition, carbofuran is being banned as of 1995 for use on rice due to adverse effect on birds (Heier 1991).

The increased use of pesticides has caused concern about ecological risks and health hazards. Moreover, pest resistance may develop when a particular chemical is frequently used. Rice water weevil resistance to carbofuran has been suspected in some areas of Louisiana because of repeated use over 20 yr. In some instances, even when the objectives of the primary pest control have been satisfactorily completed, outbreaks of secondary pests, normally of no economic concern, often take place. An example of secondary pest outbreaks has occurred in rice fields in Asia where the use of various insecticides such as BHC and parathion has brought the primary pest, the rice stem borer (C. suppressalis), under control but populations of planthoppers and leafhoppers have increased dramatically (Heinrichs et al. 1982). The hoppers (secondary pests) have developed resistance to organophosphates and
carbamates and, in general, have become difficult to control with insecticides (Heinrichs 1979, Lin et al. 1979, Kilin et al. 1981, Reissig et al. 1982). In addition, insecticides may be cost prohibitive for some small scale farmers, especially in developing countries.

In order to minimize environmental hazards due to excessive use of insecticides, entomologists and breeders have been engaged in cooperative research to develop insect resistant cultivars with agronomically desirable characteristics. The combination of resistant cultivars, cultural practices, and biological control with minimum but effective insecticide treatment will result in reduction in the frequency of insecticide application, or both.

Several attempts have been made to identify sources of rice resistance to insect pests. Heinrichs et al. (1985) listed over 30 rice insects for which screening techniques have been developed and sources of resistance have been identified. Breeding for resistance to rice insects began only two decades ago. However, the cultivation of high yielding insect resistant cultivars is one of the major control tactics in the integrated management of rice insects in many countries, including Bangladesh, China, Colombia, Cuba, India, Indonesia, Korea, Philippines, Solomon Islands Sri Lanka, Thailand and Vietnam (Heinrichs 1986). Most research efforts have concentrated on insects posing more serious problems such as planthoppers,
leafhoppers, stem borers and the gall midge in tropical countries.

Breeding programs have included identification or selection for resistance to the brown planthopper (*N. lugens*), whitebacked planthopper (*S. furcifera*), smaller brown planthopper (*L. striatellus*) and the green leafhopper (*N. virescens*) in Asia; and the delphacid (*Sogatodes orizicola* [Muir]), in Central and South America. Heinrichs et al. (1985) reported that 47,944 lines of the IRRI germplasm collection (60,000 lines) have been screened against the green leafhopper and has yielded about 1,196 resistant lines, and 50,423 lines have been screened against the brown planthopper and yielded 555 resistant lines. Progress has been made in the development of rice cultivars with resistance to planthoppers and leafhoppers because of their economic importance as pests in Asia, the abundance of resistant donor cultivars, and the efficiency of the screening method for evaluating breeding lines. Brown planthopper resistant cultivars occupy approximately 25% of the irrigated lowland rice area in Southeast Asia.

Breeding for resistance to the gall midge, *O. oryzae*, has been conducted in India, Philippines (IRRI), Sri Lanka and Thailand (Heinrichs and Pathak 1981). In Southern India, where the gall midge was an endemic pest causing severe losses, the use of resistant cultivars has been very successful and the insect now causes no economic damage (Heinrichs and Pathak 1981).
Cultivars with low to moderate levels of resistance to stem borers, particularly *Scirpophaga incertulas* and *C. suppressalis* which are the most severe stem borers pests of rice in Asia, have also been released (Heinrichs et al. 1985). However, breeding has been complicated by the moderate levels of resistance, the polygenic nature of inheritance and the poor agronomic type of donor.

For many other rice insects, such as the lesser cornstalk borer (*Elasmopalpus lignosellus* [Zeller]), African striped stem borer (*C. zacconius*) and sugarcane borer (*D. saccharalis*), levels of resistance identified in resistant germplasm are too low for breeding purposes. It should also be pointed out that at present only a small portion of the world germplasm (approximately 100,000 lines) has been screened for resistance to most rice insect pests (Heinrichs et al. 1985). Therefore, potential still exists that screening the entire rice germplasm collection will yield lines with higher levels of resistance to some of these insect pests.

Host plant resistance as a potential strategy for control of the rice water weevil has been studied by Gifford et al. (1973, 1974), Gifford and Trahan (1975), Robinson et al. (1978, 1979, 1980, 1981, 1982), Smith et al. (1979), and Smith and Robinson (1982). Cultivars identified with resistance to the rice water weevil include Bentoc, Carangiang, Dawn, Findoc and Nira with low resistance; and Iljin, Mit Dari, Toyokuni, IR269-1-1-3,
IR404-1-3-1-1, IR404-3-2-7, IR404-6-3-10-1 and IR455-5-5-1-2 with moderate resistance (Gifford and Trahan 1975, Robinson et al. 1981, Smith and Robinson 1982). However, resistance levels in these cultivars are too low for breeding purposes. Two world collection lines designated 'WC1711', and 'CL11048', identified by Grigarick et al. (1976) as having moderate tolerance to the rice water weevil, have been used as parents in breeding program at the Rice Research Station, Crowley, Louisiana.

Host plant resistance as a means of rice water weevil control offers several advantages over chemical control. Host plant resistance has no detrimental effects on the environment and is compatible with other control methods. In many instances, resistant cultivars synergize the effects of chemical, cultural and biological controls. Jones et al. (1981, 1986) found that the combinations of the okra leaf (open leaf) and frego bract (open bract) characters in cotton improve insecticide efficiency by increasing coverage on all plant parts. Heinrichs et al. (1984) demonstrated that the brown planthopper and the white-backed planthopper became more susceptible to insecticides when they were reared on only moderately hopper-resistant rice cultivars.

Integration of plant resistance with biological control has been demonstrated. Hamm and Wiseman (1986) found that fall armyworm (S. frugiperda) larvae feeding on an artificial diet containing freeze-dried maize silks from
resistant inbred lines are more susceptible to infection and mortality from NPV than larvae fed similarly with silks from susceptible inbred lines. Cultural control tactics such as trap crops and early maturing cultivars have been effectively combined with plant resistance. Burris et al. (1983) demonstrated that the combination of a trap crop, the early maturing, okra leaved cotton breeding line (La 1363 Lsne), and a nonpreferred cotton breeding line (La 81-560FN) resistant to the boll weevil (Anthomonous grandis grandis Boheman) was effective in suppressing boll weevil populations.

Plant resistance is also less costly than insecticidal control because it offers the grower the advantage of genetically incorporated insect control for the cost of the seed alone (Smith 1989). In addition if resistance is combined with the use of insecticide, the costs of insecticidal control and insecticide residue problems are greatly reduced (Smith 1989). Thus, host plant resistance represents a potentially useful pest control strategy. Improved screening techniques need to be developed, and sources of resistance to rice water weevil need to be identified and used in a breeding program aimed at developing commercially adapted cultivars. The general objective of this study is to evaluate rice germplasm lines for resistance to the rice-water weevil for potential use in rice breeding programs.
References - Literature Review


Bowling, C. C. 1967b. Test with insecticides as seed treatments to control rice water weevil. J. Econ. Entomol. 60: 18-19.


Hamm, J. J. and B. R. Wiseman. 1986. Plant resistance and nuclear polyhedrosis virus for suppression of the fall
armyworm (Lepidoptera: Noctuidae). Fla. Entomol. 69: 549-559.


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.

Arkansas Agricultural Experiment Station Bulletin 299.

Jones, J. E., D. James, F. E. Sistler, and S. J. Stringer. 
1986. Spray penetration of cotton canopies as affected 
by leaf and bract isolines. La. Agric. 29: 15-17.

Jones, J. E., W. D. Caldwell, D. T. Bowman, J. M. Brand, A. 
Coco, J. G. Marshall, D. J. Boquet, R. Hutchinson, W. 
improved open-canopy cotton. La. Agric. Exp. Sta. 
Circ. 114. 14 pp.

pp 439-469 In Bor S. Luh, Ed., Rice: production and 
utilization. AVI Publishing Company, Inc., Westport, 
Connecticut.

Khan, M. Q. 1964. Control of paddy stem borers by cultural 
practices. In The major insect pests of rice plant, 
IRRI Manila, The Hopkins Press, Baltimore, Maryland, 
pp. 360-390.

carbamate resistance in the brown planthopper, 
Nilaparvata lugens (Stal) (Homoptera: Delphacidae). 

Entomol. 24: 279-312.

Knabke, J. J. 1973. Diapause in the rice water weevil, 
Lissorhoptrus oryzophilus Kuschel (Coleoptera: 
Curculionidae in California. Ph D dissertation, 
University of California, Davis.

Kuschel, G. S. V. D. 1951. Review of Lissorhoptrus LeConte 
and Neighboring genera of America. Revista Chilena de 
Entomologia. 1: 23-74.

Lange, W. H. and A. A. Grigarick. 1959. The rice water 

Lin, Y. H., C. N. Sun, and H. T. Feng. 1979. Resistance of 
Nilaparvata lugens to MIPC and MTMC in Taiwan. J. 
Econ. Entomol. 72: 901-903.

Lu, J. J. and T. T. Chang. 1980. Rice in its temporal and 
spacial perspectives, pp. 1-74. In Bor S. Luh, Ed., 
Rice: production and utilization. AVI Publishing 


Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


Tucker, E. S. 1912. The rice water weevil and methods for its control. USDA Bureau Entomol. Circular 152.

CHAPTER I

ASSESSMENT OF LOUISIANA RICE BREEDING LINES FOR TOLERANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)
The rice water weevil, Lissorhoptrus oryzophilus Kuschel, is the most damaging insect pest of rice (Oryza sativa L.) in Louisiana and other rice growing areas of the United States. The rice water weevil is also a pest in Japan and Korea, because of its accidental introduction in 1976 (Hirao 1978). The biology and behavior of the rice water weevil has been extensively studied by Tucker (1912), Isely and Schwardt (1934), Bowling (1967, 1972) and Cave and Smith (1983). Adult rice water weevils migrate into rice fields annually and produce distinctive slit-like longitudinal feeding scars on rice leaves. Although leaf feeding damage caused by adult weevils has been reported to be of minor importance, feeding damage inflicted on seedlings can cause plantlets to die, resulting in stand reduction (Ingram 1927).

Economic damage to rice is primarily caused by larval pruning of the root system (Isely and Schwardt 1934, Newsom and Swanson 1962). Adult females either crawl down or swim to the leaf sheath below the water line, where oviposition takes place. Most eggs are inserted into the leaf sheath tissue above the crown. After eclosion, first instars mine the leaf sheath for approximately 1 d, emerge, and drift down through the water to the soil surface (Bowling 1972). Larvae then enter the soil and feed on the roots until pupation, which results in stunting of young plants, thereby causing lodging and yield reduction in mature plant stands (Webb 1914, Bowling 1967). The total annual loss in
Louisiana attributed to this pest is estimated to be $10 million (Smith et al. 1986).

The principal means of rice water weevil control has been the application of insecticides directed against the larval stage. Aldrin was the most commonly used insecticide for control of the rice water weevil in the 1950's and early 1960's (Bowling 1967). The rice water weevil became resistant to aldrin in 1964-65 in Louisiana (Graves et al. 1967). Currently, carbofuran is the only insecticide registered for control of the rice water weevil. However, the Environmental Protection Agency has revoked the registration of granular carbofuran for pest control on grain crops and thus, carbofuran may be lost to the rice industry in 1995 (Heier 1991).

Host plant resistance, as a means of rice water weevil control, has been investigated by Gifford et al. (1973, 1974), Gifford and Trahan (1975), Robinson et al. (1978, 1979, 1980, 1981, 1982), Smith et al. (1979), Smith and Robinson (1982) and N'Guessan et al. (1990a, 1990b 1990c). Only moderate and low levels of resistance to the rice water weevil have been identified in a few exotic lines (Gifford and Trahan 1975, Grigarick et al. 1976, Robinson et al. 1981, Smith and Robinson 1982). The utilization of resistant cultivars is an alternative to chemical control and/or resistant cultivars may be used in combination with other control tactics in an integrated pest management
approach. This study was designed to evaluate Louisiana rice breeding lines for tolerance to the rice water weevil.

Materials and Methods

Preliminary field screening of 40 Louisiana rice breeding lines in 1990 for resistance to the rice water weevil yielded several lines with potential tolerance. The six most promising lines were selected for further evaluation in 1991 and 1992 to confirm the level of tolerance to the rice water weevil. Research was conducted under field conditions at the Rice Research Station near Crowley, Louisiana. The experimental design was a split-plot with six replicates. One susceptible commercial cultivar (Mars) and one world collection line (WC1403) with a moderate level of tolerance were used as susceptible and tolerant checks respectively. Within each replicate, each treatment (rice line) was divided into two units organized in strips, one treated with insecticide and the other not treated. Thus, the whole plots were the different rice lines and the sub-plots were two levels (treated, untreated) of insecticide. The cultivars were drill seeded (3 g/row) on 17 June 1991 and 8 May 1992. Plot size was six 2-m rows (2 m by 1.22 m), spaced 0.9 m between strips and 0.5 m within strips. Row spacing was 0.25 m. Propanil (4.5 Kg [AI] per ha; Rohm & Haas Company, Philadelphia, Pa.) herbicide was applied to all plots on 29 June 1991 and 1 June 1992. Before permanent flood (2 July 1991 and 5 June 1992), fertilizer (134:67:67 kg [AI] per ha of N P K)
was applied to all plots (1 July 1991 and 4 June 1992). Carbofuran (FMC, Philadelphia, Pa.) at 1.12 Kg [AI] per ha was applied to the treated units with a shaker jar (3 and 17 July 1991 and 8 and 18 June 1992).

Twenty-one d after permanent flood, three soil-root core samples (9.2 cm diam. by 7.6 cm deep) were taken from each plot and individually bagged in prelabeled bags to assess rice water weevil larval population. The soil was washed off the roots of the plants through a 40-mesh copper sieve using pressured water. The residue was placed in a saturated sodium chloride solution and floating rice water weevil larvae and pupae were counted. Root damage was assessed with a visual rating of the root system. Root damage ratings were evaluated 28, 35 and 42 d after permanent flood. Rice plant samples (three plants/plot) were taken from each plot, the soil was washed off the roots and a score was given to the root system using a 0 to 5 scale; where, 0 = no root damage, 1 = 1/3 of root system pruned with regrowth, 2 = 1/3 of root system pruned with no root regrowth, 3 = 2/3 of root system pruned and root regrowth, 4 = entire root system pruned with root regrowth, and 5 = entire root system damaged with no root regrowth.

At maturity but before harvest, a representative height (three plants/plot) was measured from each plot to assess the difference in growth between the treated and untreated plots. All plots were harvested (16 October 1991 and 3 September 1992) and the grain yield was determined to
assess reduction due to root damage. Percent height (% Ht diff) and percent yield (% Yd diff) differences were calculated as follow: % Ht Diff = ([treated Ht - untreated Ht] / treated Ht) x 100; and % Yd Diff = ([treated Yd - untreated Yd] / treated Yd) x 100.

The data were subjected to analysis of variance (ANOVA) using SAS General Linear Model Procedure (SAS Institute 1985). The means were separated using Tukey's Studentized Range (HSD) test. A paired T Test (Proc means, percent difference) was used to compare the treated and untreated variables. Root data were analyzed as a split-split-plot in which date (the dates on which root damage ratings were performed) was the sub-sub-plot.

Results

Insecticide significantly reduced rice water weevil larval population in the treated plot in 1991 (df = 1,5; F = 524.7; P < 0.0001) and 1992 (df = 1,5; F = 705.7; P < 0.0001). The level of rice water weevil larval infestation was higher in 1991 than in 1992 (Table 1.1). Although significant (P < 0.05) differences were found among the lines evaluated in the untreated plots, none of the test lines had significantly lower rice water weevil larval populations than the susceptible check (Mars), indicating that antibiosis or antixenosis is not the mechanism of resistance. In addition, there was no line by insecticide interaction for larval population, suggesting that larval control by the carbofuran treatment was the same for all
Table 1.1. Mean number of rice water weevil larvae in Louisiana breeding lines evaluated for tolerance, Crowley, La., 1991-1992.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8720906</td>
<td>47.3 ± 3.0ab</td>
<td>9.0 ± 1.8a</td>
<td>38.5 ± 2.6a</td>
<td>2.7 ± 0.9a</td>
</tr>
<tr>
<td>8721317</td>
<td>42.4 ± 1.9ab</td>
<td>9.3 ± 2.6a</td>
<td>34.4 ± 3.1ab</td>
<td>2.7 ± 0.6a</td>
</tr>
<tr>
<td>8721937</td>
<td>45.2 ± 2.8ab</td>
<td>5.6 ± 0.9a</td>
<td>39.4 ± 1.7a</td>
<td>2.8 ± 0.5a</td>
</tr>
<tr>
<td>8721941</td>
<td>48.7 ± 2.5ab</td>
<td>7.9 ± 2.2a</td>
<td>36.1 ± 1.9ab</td>
<td>1.9 ± 0.4a</td>
</tr>
<tr>
<td>8722239</td>
<td>40.4 ± 2.3ab</td>
<td>10.3 ± 2.4a</td>
<td>29.6 ± 2.0ab</td>
<td>2.5 ± 0.4a</td>
</tr>
<tr>
<td>8723514</td>
<td>38.5 ± 4.2ab</td>
<td>6.8 ± 0.8a</td>
<td>25.3 ± 2.3b</td>
<td>1.7 ± 0.5a</td>
</tr>
<tr>
<td>Mars</td>
<td>41.4 ± 2.7ab</td>
<td>8.8 ± 1.9a</td>
<td>33.4 ± 2.7ab</td>
<td>4.3 ± 1.0a</td>
</tr>
<tr>
<td>Lemont</td>
<td>34.2 ± 4.7b</td>
<td>6.8 ± 2.7a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>WC1403</td>
<td>50.4 ± 3.6ab</td>
<td>7.5 ± 1.0a</td>
<td>36.5 ± 2.5ab</td>
<td>1.4 ± 0.4a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P < 0.05, Tukey's Studentized Range (HSD) Test [SAS Institute 1985]).
the lines evaluated. Larval populations in carbofuran treated plots ranged from 5.6 to 10.3 larvae/core in 1991 and from 1.4 to 4.3 larvae/core in 1992. Larvae in the treated plots were predominantly small at the time of sampling.

The root damage ratings in the untreated plots at 28, 35 and 42 d postflood are shown in Figs. 1.1 and 1.2 for 1991 and 1992, respectively. Root damage ratings were relatively high for most of the cultivars at 28 d postflood in 1991 and 1992. There was no line by insecticide interaction for root ratings, but there was a significant ($P < 0.05$) interaction between lines and date of sampling, suggesting that change in root biomass from 28 d postflood to 42 d postflood was variable among lines. Root damage ratings for the rice lines 8720906, 8722239 and 8721937 decreased from 28 d to 42 d postflood in 1991 and 1992, suggesting that these lines recovered from root pruning damage. Root damage ratings in the treated plots did not exceed two in 1991 and 1992, suggesting that only 1/3 or less than 1/3 of the roots in the treated plots were pruned (Figs. 1.3 and 1.4) compared with over 2/3 or the entire root system pruned in the untreated plots (Figs. 1.1 and 1.2).

Plant height and yield data in the treated and untreated plots and the height and yield differences between treated and untreated plots for 1991 and 1992 are presented in Tables 1.2 and 1.3, respectively. There were
Fig. 1.1. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
ROOT DAMAGE RATING

CULTIVAR/LINE

28 d POSTFLOOD  35 d POSTFLOOD  42 d POSTFLOOD
Fig. 1.2. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 1.3. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 1.4. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Table 1.2. Height and yield of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991.

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>8720906</td>
<td>100.9</td>
<td>91.4</td>
</tr>
<tr>
<td></td>
<td>(204.5)</td>
<td>(351.9)</td>
</tr>
<tr>
<td>8721317</td>
<td>104.8</td>
<td>97.4</td>
</tr>
<tr>
<td></td>
<td>(198.2)</td>
<td>(98.0)</td>
</tr>
<tr>
<td>8721937</td>
<td>113.3</td>
<td>102.4</td>
</tr>
<tr>
<td></td>
<td>(212.1)</td>
<td>(317.3)</td>
</tr>
<tr>
<td>8721941</td>
<td>96.2</td>
<td>86.3</td>
</tr>
<tr>
<td></td>
<td>(121.2)</td>
<td>(209.7)</td>
</tr>
<tr>
<td>8722239</td>
<td>113.1</td>
<td>107.4</td>
</tr>
<tr>
<td></td>
<td>(179.6)</td>
<td>(330.3)</td>
</tr>
<tr>
<td>8723514</td>
<td>96.1</td>
<td>90.4</td>
</tr>
<tr>
<td></td>
<td>(151.0)</td>
<td>(312.6)</td>
</tr>
<tr>
<td>MARS</td>
<td>107.2</td>
<td>97.5</td>
</tr>
<tr>
<td></td>
<td>(118.8)</td>
<td>(352.1)</td>
</tr>
<tr>
<td>LEMONT</td>
<td>96.9</td>
<td>79.8</td>
</tr>
<tr>
<td></td>
<td>(239.6)</td>
<td>(198.6)</td>
</tr>
<tr>
<td>WC1403</td>
<td>113.5</td>
<td>102.5</td>
</tr>
<tr>
<td></td>
<td>(218.9)</td>
<td>(229.4)</td>
</tr>
</tbody>
</table>

<sup>1</sup> % Ht diff = ([treated height - untreated height]/treated height)*100.

<sup>2</sup> % Yd diff = ([treated yield - untreated yield]/treated yield)*100.

* Indicates significant at P < 0.05 (Paired T test).

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range (HSD) Test [SAS Institute 1985]). Standard Error is shown below the grain yield in parentheses.
Table 1.3. Height and yield of Louisiana breeding lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992.

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>8720906</td>
<td>99.7</td>
<td>95.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8721317</td>
<td>103.0</td>
<td>101.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8721937</td>
<td>117.2</td>
<td>106.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8721941</td>
<td>100.3</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8722239</td>
<td>111.8</td>
<td>107.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8723514</td>
<td>103.9</td>
<td>97.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>106.7</td>
<td>101.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC1403</td>
<td>130.2</td>
<td>124.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$ % Ht diff = ([(treated height - untreated height)/treated height] *100.

$^2$ % Yd diff = ([(treated yield - untreated yield)/treated yield] *100.

* Indicates significant at $P < 0.05$ (Paired T test).

Means followed by the same letter within column are not significantly different ($P > 0.05$, Tukey's Studentized Range (HSD) Test [SAS Institute 1985]). Standard Error is shown below the grain yield in parentheses.
significant ($P < 0.05$) line by insecticide interactions for plant height and grain yield during both years, suggesting that height and yield response to carbofuran treatment differed among the lines evaluated. In addition line effect was significant on height and grain yield in 1991 (height, $df = 9,45$; $F = 24.62$, $P < 0.0001$; yield, $df = 9,45$; $F = 15.52$, $P < 0.0001$) and 1992 (height, $df = 7,34$; $F = 60.58$, $P < 0.0001$; yield, $df = 7,35$; $F = 11.25$, $P < 0.0001$). Plants in the treated plots were significantly ($P < 0.05$) taller than plants in the untreated plots during both years for all the lines evaluated except 8721941 in 1991 and 8721317 in 1992.

Lines 8720906 and 8721937 averaged more grain yield than the susceptible cultivar, Mars, during the 2-yr study. Furthermore, lines 8720906, 8721937 and 8722239 did not show significant ($P > 0.05$) yield differences between the treated and untreated plots in 1991 and 1992 (Tables 1.2 and 1.3), indicating that they are tolerant to the rice water weevil. Lines 8720906 and 8721937 also averaged higher grain yields than the moderately tolerant world collection line (WC1403) during both years. However, it should be noted that WC1403 is very susceptible to blast in Louisiana and this may have contributed to the low performance reflected in lack of root regrowth and low yield during this study.
Discussion

Painter (1951) defined tolerance as the mechanism of resistance by which the host plant can grow or reproduce normally or compensate for injury while supporting an insect pest population that severely damages a susceptible host. Tolerance is determined by comparing the production of plant biomass (yield) in insect-infested and noninfested plants of the same cultivar (Smith 1989). Comparisons in this study indicated that Louisiana breeding lines 8720906, 8721937 and 8722239 were tolerant to the rice water weevil. Statistically, these lines produced equal yields in the treated and untreated plots while supporting high rice water weevil larval populations in the untreated plots. This, in part, was a result of increased root regrowth after heavy pruning by rice water weevil larvae.

These results corroborate the findings of Gifford et al. (1974) and Latson and Trahan (1977), who suggested that root damage recovery contributed to rice water weevil tolerance in rice. These researchers used root volume (water displacement of roots), root dry weight and root rating to assess tolerance in rice to the rice water weevil. Gifford and Trahan (1975) reported three exotic cultivars (WC1403, WC1349, WC1815) to be moderately tolerant to the rice water weevil. They found that root data recorded at 30 and 38 d postflood indicated WC1403, WC1349 and WC1815 had heavy root pruning at 30 d postflood; however, at 38 d postflood, the three lines showed good
root regrowth and high total root biomass that resulted in higher grain yield relative to the other lines and cultivars evaluated. However, in our preliminary screening test in 1990, we found that root volume and root dry weight cannot be adequately used to assess tolerance because when roots are washed using a pressured water system, newly grown roots may break-off and thus, produce an inaccurate estimate of root biomass. In addition, soil residues on the root may increase dry weight, especially when rice is grown in a clay type soil.

Tolerance to planthoppers was found to be expressed as the ability of tolerant cultivars to survive and produce a higher percentage of productive tillers than susceptible cultivars (Ho et al. 1982). The high yield observed in lines 8720906 and 8721937 in the untreated plots could be a result of increased tillering due to root recovery. Grigarick (1974) found that tolerance in 6112 from I.R.R.I. was manifested in high root biomass and increased tillering. Root damage restricts the plant's ability to uptake nutrients from the soil. Regrowth of new roots or regeneration of damaged roots reestablished the plant's ability to uptake nutrients, resulting in normal plant growth and high yield in plants in the untreated plots.

The significant height differences, found between plants in treated and untreated plots in some lines, may be due to the heavy root pruning in the early vegetative growth in the untreated plots. However, carbofuran has
been previously found to stimulate plant growth, although varietal response is variable (Venugopal 1981). Thus, carbofuran may have played a role in height increase in the treated plots.

The rice water weevil tolerant lines (8720906 and 8721937) identified in this study also have better yield potential than the susceptible cultivar, Mars. Since agronomic characteristics of the plants or disease resistance were not evaluated, these lines cannot be recommended for use as commercial cultivars. Nevertheless, lines 8720906 and 8721937 should be evaluated by a plant breeder for agronomic characteristics and determine if they are suitable candidates for release as commercial cultivars. These lines could also be crossed with other susceptible commercial cultivars to incorporate the rice water weevil tolerance into new, resistant cultivars with agronomically suitable characteristics.
References - Chapter I


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.


Latson, L. N. and G. B. Trahan. 1977. Host plant resistance to the rice water weevil, pp. 113-139. In 69th Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.


N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening tissue culture lines for resistance to the rice water weevil, pp. 324-325. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990c. Screening rice lines for resistance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


Tucker, E. S. 1912. The rice water weevil and methods for its control. USDA Bureau Entomol. Circular 152.


CHAPTER II

EVALUATION OF RICE TISSUE CULTURE LINES FOR RESISTANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)
In the rice-growing areas of the United States and recently Japan and Korea, the rice water weevil (Lissorhoptrus oryophilus Kuschel) has been the most destructive insect pest of rice, *Oryza sativa* L. (Newsom and Swanson 1962, Hirao 1978). Adult weevils feed on the rice plant by rasping away the leaf epidermis, leaving skeletonized longitudinal slit-like scars. Although leaf feeding damage caused by adult weevils has been reported to be of minor importance, damage inflicted on seedlings can cause the plantlet to die and result in stand reduction (Ingram 1927). Larval pruning of the rice root system causes the most economic damage (Isely and Schwardt 1934). Root damage by the larvae causes stunting of young plants, and lodging and yield loss in mature plants (Bowling 1967). Losses to the Louisiana rice industry attributable to damage by this pest are estimated at $10 million annually (Smith et al. 1986).

For the last two decades, a single postflood broadcast application of granular carbofuran (0.56 kg [AI]/ha) has been the principal means of control of the rice water weevil (Gifford et al. 1970). Registration of granular carbofuran for pest control on grain crops has been revoked and, therefore, carbofuran may be lost to the rice industry by 1995 (Heier 1991). Isely and Schwardt (1934), Robinson et al. (1980a), Morgan et al. (1989) and Hesler et al. (1992) found that rice field drainage controlled larval populations; however, data indicated that water management
is impractical because of fertilizer loss, weed problems and plant water stress which may result in yield reduction. Nevertheless, Quisenberry et al. (1992) compared the use of carbofuran and water management, and conducted a cost/benefit analysis to conclude that water management has potential as an economical pest management tool for control of the rice water weevil.

A potential alternative or addition to chemical and cultural control of the rice water weevil is the use of host plant resistance. The development and utilization of rice cultivars resistant to the rice water weevil would offer savings in production costs and reduced impacts on the environment. Several thousand rice lines have been screened for resistance to the rice water weevil by Gifford et al. (1973), Gifford and Trahan (1975), Robinson et al. (1978, 1979, 1980b, 1981, 1982), Smith et al. (1979) and N'Guessan et al. (1990a, 1990b, 1990c). However, only a few exotic rice genotypes with moderate tolerance have been identified in California by Grigarick et al. (1976) and in Louisiana by Gifford and Trahan (1975). Smith and Robinson (1982) reported five cultivars of Philippine origin to be moderately resistant to the rice water weevil larval infestation, adult feeding, or both.

Progress has been made in rice breeding programs resulting in cultivars with superior agronomic characteristics. However, there remains a pressing need for continued genetic improvements in rice especially in
developing cultivars with insect and disease resistance. As an adjunct to the successful conventional plant breeding procedures used to improve rice, biotechnology offers a number of new approaches to facilitate breeding rice for resistance to insects and diseases or yield. Tissue culture is a technique by which plants are regenerated from the culture of somatic plant tissues, such as roots, stems and leaves (Croughan and Robinson 1990, Chu and Croughan 1990). Plants produced by this technique frequently differ genetically from the original donor plant (Croughan and Robinson 1990). Mutations frequently induced in rice with this procedure include change in plant height, days to maturity, tillering, leaf shape and display, grain size, panicle size, and degree of sterility; however, mutations also can produce plants resistant to insects and/or diseases (Croughan and Robinson 1990). Several new cultivars of rice have already been developed from laboratory-cultured plant cells and tissue in China and the United States (Croughan and Robinson 1990); however, there is no information regarding insect resistance. The present study was initiated to evaluate rice regenerated from tissue culture for resistance to the rice water weevil.

Materials and Methods

Preliminary field screening of 66 tissue culture rice lines in 1990 for resistance to the rice water weevil yielded several lines with potential resistance. Nine tissue culture lines were evaluated in 1991 and 1992 to determine
the mechanisms of resistance to the rice water weevil. Lines selected from 1990 test were separated in two groups: one group (67, 93, 112, 120, 4754) was tested specifically for tolerance and the other group (185, 244, 2051, 2232) was tested for antixenosis and/or antibiosis.

Tolerance Test. Five lines (67, 93, 112, 120, 4754) were selected for this test based on higher yields in 1990. Research was conducted under field conditions at the Rice Research Station, Crowley, LA. The experimental design was a split-plot with six replicates. Within each replicate, each treatment (rice line) was divided into two units organized in strips, one treated with insecticide and the other not treated. Thus, whole plots were the different rice lines and the sub-plots were two levels (treated, untreated) of insecticide. The lines were drill seeded (3 g per 2-m row) on 5 June 1991 and 19 May 1992. Plot size was six 2-m rows (2 m by 1.22 m), spaced 0.9 m between strips and 0.5 m within strips with 0.25 m row spacing. A susceptible cultivar (Mars) and a moderately tolerant world collection line (WC1403) were used as checks in each replicate. Propanil (4.5 Kg [AI] per ha; Rohm & Haas Company, Philadelphia, Pa.) herbicide was applied to all plots on 19 June 1991 and 9 June 1992. Before permanent flood (20 June 1991 and 12 June 1992), fertilizer (N P K at 134:67:67 kg [AI]/ha) was applied to all plots (20 June 1991 and 11 June 1992). Carbofuran (FMC, Philadelphia, Pa.) at 1.12 kg [AI]/ha was applied to the treated plots

Twenty-one d after permanent flood, three soil-root core samples (9.2 cm diam. by 7.6 cm deep) were taken from each plot and individually bagged in prelabeled bags for rice water weevil larval population assessment. The soil was washed off the roots of the plants through a 40-mesh copper sieve. The residue was placed in a saturated sodium chloride solution and the floating rice water weevil larvae and pupae were counted.

Root damage was assessed through visual rating of the root system. Rating of root damage was performed 28, 35 and 42 d after permanent flood. Rice samples (three samples/plot) were taken from each plot, the soil was washed off the roots and a score was given to the root system using a 0 to 5 scale; where, 0 = no root damage, 1 = 1/3 of root system pruned with root regrowth, 2 = 1/3 of root system pruned with no root regrowth, 3 = 2/3 of root system pruned and root regrowth, 4 = entire root system pruned with root regrowth and 5 = entire root system damaged with no root regrowth.

At maturity, before harvest, a representative height (three samples/plot) was taken from each plot to assess the difference in growth between the treated and untreated plots. All plots were harvested (2 October 1991 and 10 September 1992) and the grain yield was determined to assess yield reduction due to root damage. Percent height
difference (% Ht diff) and percent yield loss (% Yd Loss) were calculated as follow: % Ht Diff = ([treated Ht - untreated Ht]/treated Ht) x 100; and % Yd Loss = ([treated Yd - untreated Yd]/treated Yd) x 100.

The data were subjected to analysis of variance (ANOVA) using SAS General Linear Model Procedure (SAS Institute 1985). The means were separated using Tukey's Studentized Range (HSD) test. A paired T test (Proc means, percent difference) was used to compare the treated and untreated variables. Root data were analyzed as a split-split-plot in which root sampling date was the sub-sub-plot.

Antixenosis Test. Four lines (185, 244, 2051, 2232) were selected for this test based on observed low numbers of rice water weevil larvae on roots in 1990. In 1991, a choice experiment was conducted in the greenhouse. The greenhouse conditions were ambient to temperatures and photoperiod in May-July in Baton Rouge, Louisiana. The four lines and a susceptible check cultivar (Mars) were planted in separate pots (approximately 13 cm diam. by 10 cm deep) filled with Crowley silt loam soil. Before permanent flood (established 21 d from the date of planting), plants were thinned to six plants per pot. The pots were placed in a basin made of a 2.1 x 1.4 x 0.3 m wooden frame secured with a visquin (plastic) to hold the flood water. A pot of each line was placed randomly in a circular manner and caged. Cages were made of cylindrical
metal frames (0.5 m diam by 0.62 m high) covered with a 40 mesh vinyl screen that prevented adult weevils from escaping. Adult rice water weevils in copula were collected from the field and confined within the cages (16 insects/cage) for a period of 1 wk. The cages and adult weevils were removed to allow plants to develop. All plants were infested the same day at permanent flood. The experimental design was a randomized block with eight replicates. Each cage constituted one replicate. Twenty-one d post-infestation, the content of each pot was washed through a 40-mesh copper sieve. The residue was placed in a saturated sodium chloride solution and floating rice water weevil larvae and pupae were classified as small (0-3 mm), medium (3-6 mm) and large (large (6-10 mm) + pupa).

The four lines selected for antixenosis were also planted (17 June 1992) in the field in a randomized block design with five replicates. Agricultural practices were similar to that in the tolerance test (permanent flood established on 8 July and propanil applied on 23 June and 6 July). Contrary to the tolerance test, the plot size was single 2-m row. Three samples were taken from each plots and processed in according to the procedures described for the choice experiment to assess rice water weevil larval population levels.

Both greenhouse and field data were analyzed as randomized block design using SAS General Linear Model
Procedure (SAS Institute 1985). The means were separated using Tukey's Studentized Range (HSD) test.

Results

Tolerance Test. Both line and insecticide effects were significant on rice water weevil larval populations in 1991 (line: df = 6,30, F = 6.78, P < 0.0001; insecticide: df = 1,5, F = 612.76, P < 0.0001) and 1992 (line: df = 6,30, F = 4.92, P < 0.0013; insecticide: df = 1,5, F = 353.73, P < 0.0001). There was a significant line by insecticide interaction for larval population during both years, suggesting that the lines evaluated responded differently to carbofuran treatment. Thus, some of the lines may be resistant to the rice water weevil. However, larval populations were relatively high for all the lines in the untreated plots and none of the test lines had significantly lower larval population than the susceptible cultivar, Mars in 1991 (Table 2.1). The population trends were relatively consistent for both years. Line 120 was the least infested in both years, averaging significantly lower larval population than Mars in 1992 (Table 2.1). The most heavily infested line was 4754, averaging 65.7 and 61.7 larvae/core, respectively, in 1991 and 1992. Mars, the susceptible cultivar used as a check, averaged 48.88 and 56.05 larvae/core, respectively, in 1991 and 1992. Larval populations were relatively low in the treated plots and did not differ among the lines evaluated for either of the two years (Table 2.1).
Table 2.1. Mean number of rice water weevil larvae per core in rice tissue culture lines evaluated for tolerance, Crowley, La., 1991-1992.

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>1991</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated</td>
<td>Treated</td>
</tr>
<tr>
<td>67</td>
<td>50.3 ± 3.6ab</td>
<td>8.8 ± 1.0a</td>
</tr>
<tr>
<td>93</td>
<td>40.3 ± 2.3b</td>
<td>8.1 ± 1.2a</td>
</tr>
<tr>
<td>112</td>
<td>39.5 ± 3.1b</td>
<td>9.5 ± 1.0a</td>
</tr>
<tr>
<td>120</td>
<td>37.6 ± 3.6b</td>
<td>8.9 ± 1.0a</td>
</tr>
<tr>
<td>4754</td>
<td>65.6 ± 3.0a</td>
<td>10.0 ± 1.0a</td>
</tr>
<tr>
<td>Mars</td>
<td>48.8 ± 3.5b</td>
<td>10.7 ± 1.2a</td>
</tr>
<tr>
<td>WC1403</td>
<td>51.2 ± 3.0ab</td>
<td>8.4 ± 0.9a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range (HSD) Test [SAS Institute 1985]).
Plants in the treated plots were significantly (P < 0.05) taller than plants in the untreated plots during both years (Table 2.2). There was no interaction between line and insecticide for plant height, indicating that height increase due to carbofuran treatment was the same for all the lines tested.

Root damage ratings in the untreated plots were high for most of the lines at 28 d postflood in 1991 and 1992 (Figs. 2.1 and 2.2). There was no line by insecticide interaction for root ratings, but there was a significant interaction between line and root sampling date, indicating that change in ratings from 28 d postflood to 42 d postflood was not the same for all the lines evaluated. There was a significant decrease in root damage ratings for lines 67, 112 and 4754 in 1991 and lines 93, 112, and 4754 in 1992 from 28 d to 42 d postflood, suggesting that these lines recovered from root pruning damage. Root damage ratings in the treated plots were relatively constant within sampling dates and did not exceed a rating of two for any of the dates (Fig. 2.3 and 2.4). This indicates that less than 1/3 of the roots were pruned in the treated plots compared to almost the entire root system pruned in the untreated plots.

Yield data for 1991 and 1992 are presented in Figs. 2.5 and 2.6 respectively. There was a significant line by insecticide interaction for grain yield during both years (1991: df = 6,34; F = 3.7; P < 0.0061; 1992: df = 6,34; F =
Table 2.2. Mean height and percent height difference of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991-1992.

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>1991 Treated</th>
<th>1991 Untreated</th>
<th>% Ht diff&lt;sup&gt;1&lt;/sup&gt;</th>
<th>1992 Treated</th>
<th>1992 Untreated</th>
<th>% Ht diff&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>114.0</td>
<td>106.6</td>
<td>6.5*</td>
<td>114.0</td>
<td>109.3</td>
<td>4.1*</td>
</tr>
<tr>
<td>93</td>
<td>121.0</td>
<td>111.3</td>
<td>8.0*</td>
<td>122.0</td>
<td>115.6</td>
<td>5.2*</td>
</tr>
<tr>
<td>112</td>
<td>117.3</td>
<td>111.1</td>
<td>5.1*</td>
<td>123.2</td>
<td>115.2</td>
<td>6.3*</td>
</tr>
<tr>
<td>120</td>
<td>109.6</td>
<td>102.7</td>
<td>6.2*</td>
<td>112.0</td>
<td>103.9</td>
<td>7.3*</td>
</tr>
<tr>
<td>4754</td>
<td>112.1</td>
<td>105.0</td>
<td>6.1*</td>
<td>112.3</td>
<td>104.9</td>
<td>6.6*</td>
</tr>
<tr>
<td>Mars</td>
<td>113.3</td>
<td>105.6</td>
<td>6.8*</td>
<td>113.7</td>
<td>107.8</td>
<td>5.2*</td>
</tr>
<tr>
<td>WC1403</td>
<td>128.7</td>
<td>120.9</td>
<td>6.1*</td>
<td>124.9</td>
<td>119.0</td>
<td>4.6*</td>
</tr>
</tbody>
</table>

<sup>1</sup> % Ht diff = ([treated height-untreated height]/treated height)*100.
* Indicates significant at P < 0.05 (Paired T test).
Fig. 2.1. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 2.2. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 2.3. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicate means are not significantly different (P > 0.05), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 2.4. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different (P > 0.05), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
ROOT DAMAGE RATING

28 d POSTFLOOD
35 d POSTFLOOD
42 d POSTFLOOD

CULTIVAR/LINE

ROOT DAMAGE RATING

67
93
112
120
4754
MARS
1403

0
1
2
3
4
5
Fig. 2.5. Yield of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars within lines with the same letters indicates means are not significantly different (P > 0.05, Paired T test [SAS Institute 1985]).
Fig. 2.6. Yield of rice tissue culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars within lines with the same letters indicates means are not significantly different ($P > 0.05$, Paired T test [SAS Institute 1985]).
GRAIN YIELD (X 1000 kg/ha)

<table>
<thead>
<tr>
<th>CULTIVAR/LINE</th>
<th>UNTREATED</th>
<th>TREATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>7</td>
<td>a</td>
</tr>
<tr>
<td>93</td>
<td>6</td>
<td>b</td>
</tr>
<tr>
<td>112</td>
<td>6</td>
<td>a</td>
</tr>
<tr>
<td>120</td>
<td>5</td>
<td>a</td>
</tr>
<tr>
<td>4754</td>
<td>8</td>
<td>a</td>
</tr>
<tr>
<td>MARS</td>
<td>9</td>
<td>a</td>
</tr>
<tr>
<td>1403</td>
<td>8</td>
<td>a</td>
</tr>
</tbody>
</table>
3.96; \( P < 0.0041 \), indicating that yield response to carbofuran treatment was not the same for all the lines evaluated. There were also significant yield differences among the lines tested in 1991 (\( df = 6,29; F = 30; P < 0.0001 \)) and 1992 (\( df = 6,29; F = 26.07; P < 0.0001 \)). Lines 112 and 4754 averaged higher yields than the susceptible check (Mars) during both years. When yields of untreated and treated plots were compared for individual lines, lines 112 and 4754 did not show significant difference between treated and untreated plots, suggesting that these lines are tolerant to the rice water weevil. In addition, yield differences between treated and untreated plots were lowest for lines 112 and 4754 (Figs. 2.7 and 2.8). These results were consistent for both years.

**Antixenosis Test.** Results from the greenhouse and field experiments are presented in Figs. 2.9 and 2.10, respectively. For each line tested, the number of small, medium, and large (large + pupae) larvae were assessed and the total population levels were determined. Although infestation in the greenhouse was twice as high as infestation in the field, results from the field in 1992 were consistent with the greenhouse study. The total larval populations differed significantly (greenhouse, \( df = 4,28; F = 3.72; P < 0.01 \); field, \( df = 5,80; F = 3.50; P < 0.0066 \)) among the lines evaluated. Lines 244 and 2232 were the least infested in both experiments. These lines also had significantly (\( P < 0.05 \)) lower numbers of rice water
Fig. 2.7. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1991. Bars with * indicates that yield loss is significant. Paired T test results were: 67, $T = 6.10, P < 0.0017$; 93, $T = 3.18, P < 0.02$; 112, $T = 1.88, P > 0.11$; 120, $T = 5.03, P < 0.004$; 4754, $T = 1.36, P > 0.23$; Mars, $T = 4.09, P < 0.009$; WC1403, $T = 3.86, P < 0.01$. 
Fig. 2.8. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice tissue culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992. Bars with * indicates that yield loss is significant. Paired T test results were: 67, $T = 3.09, P < 0.02$; 93, $T = 4.51, P < 0.006$; 112, $T = 1.66, P > 0.15$; 120, $T = 3.31, P < 0.02$; 4754, $T = 1.21, P > 0.27$. Mars, $T = 5.83, P < 0.002$; WC1403, $T = 2.48, P > 0.052$. 
Percent Yield Loss

<table>
<thead>
<tr>
<th>Cultivar/Line</th>
<th>67</th>
<th>93</th>
<th>112</th>
<th>120</th>
<th>4754</th>
<th>MARS</th>
<th>1403</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*</td>
<td>NS</td>
<td></td>
<td></td>
<td>NS</td>
<td>*</td>
<td>NS</td>
</tr>
</tbody>
</table>

The chart shows the percent yield loss for different cultivars/lines. The asterisk (*) indicates statistical significance, and 'NS' indicates no significant difference.
Fig. 2.9. Mean number of rice water weevil larvae and pupae per pot in rice tissue culture lines evaluated for resistance, Baton Rouge, La. 1991 (Greenhouse experiment). Bars with the same letters indicate means are not significantly different ($P > 0.05$, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]). Analysis of variance results were (df = 4,28): small, $F = 1.88$, $P > 0.42$; medium, $F = 1.34$, $P > 0.27$; large, $F = 4.75$, $P < 0.0049$; total, $F = 3.72$, $P < 0.01$. 
Fig. 2.10. Mean number of rice water weevil larvae and pupae per core in rice tissue culture lines evaluated for resistance, Crowley, La. 1992 (Field experiment). Bars with the same letters indicates means are not significantly different ($P > 0.05$; Tukey's Studentized Range [HSD] Test [SAS Institute 1985]. Analysis of variance results were (df = 5,80): small, $F = 1.16$, $P > 0.33$; medium, $F = 3.02$, $P < 0.01$; large, $F = 4.49$, $P < 0.0012$; total, $F = 3.50$, $P < 0.0066$. 
weevil larvae than the susceptible check (Mars) in the greenhouse and the field antixenosis studies, suggesting that these lines are at least moderately resistant to the rice water weevil. Lines 185 and 2051 also had lower larval populations than Mars, although differences were not significant.

The trend in larval size distribution of the test lines was similar to that of the check cultivar. In addition, all the test lines as well as the check cultivar had more large larvae than small or medium larvae in both years (Figs. 2.9 and 2.10), indicating that larval growth and development was not affected by plant resistance characteristics. This suggests that larval antibiosis was not a mechanism of resistance in the lines that showed resistance. Thus, the mechanism of resistance appeared to be antixenosis for adult oviposition since all the lines had an equal chance to be infested in the greenhouse and field experiments.

Discussion

Plant resistance to insects is relative because the degree of resistance is based on comparison to susceptible plants that are more severely damaged under similar test conditions. Plant tolerance to insects is characterized by the ability of the host plant to grow or reproduce normally while supporting an insect pest population that usually causes severe damage to a susceptible host (Painter 1951). Tolerance is determined by comparing the production of
plant biomass (yield) in insect-infested and noninfested plants of the same cultivar (Smith 1989). In the present study, determination of rice tolerance to the rice water weevil was based on comparison of treated (noninfested rice plants) and untreated plots (rice water weevil-infested rice plants). Lines 112 and 4754 sustained high numbers of larvae in the untreated plots but did not show significant yield differences between treated and untreated plots. Thus, these lines were tolerant to rice water weevil damage. Tolerance can be attributed in part to recovery from root pruning damage. The rate of root recovery may be variable among cultivars. For a cultivar with a high rate of root regrowth, plants in untreated plots may be able to recover from damage faster and produce greater numbers of tillers comparable to plants in treated plots. Ho et al. (1982) found that rice tolerance to planthoppers was expressed as the ability of tolerant cultivars to survive and produce a higher percentage of productive tillers than susceptible cultivars. Grigarick (1974) also found that tolerance in line 6112 from I.R.R.I. was expressed by high root biomass and increased tillering.

Our results corroborate the findings of Gifford and Trahan (1975) and Latson and Trahan (1977) who suggested that root damage recovery contributed to rice water weevil tolerance in rice. Gifford and Trahan (1975) reported three exotic cultivars (WC1403, WC1349, WC1815) to be moderately tolerant to the rice water weevil. They found
that these lines, which had heavy root pruning at 30 d postflood, displayed good root regrowth at 38 d postflood, and as a result produced higher grain yield compared with other lines evaluated.

The significant height differences between plants in untreated and treated plots can be attributed to the severe pruning of roots by the rice water weevil in untreated plots. However, we do not rule out the possibility of a stimulative effect of carbofuran on plant growth, especially when used at 1.12 kg [AI]/ha or higher. Thompson et al. (1991) found that rice plants in carbofuran treated (0.56 kg [AI]/ha) plots were significantly taller than plants in untreated plots and plants that were treated with a different pesticide. Venugopal (1981) reported that the effect of carbofuran can be variable and cultivar dependant.

In a previous study, Smith and Robinson (1982) found that a growth-inhibiting factor in cultivar Nira contributed to resistance to the rice water weevil. They compared larval size distribution of cultivar Nira with that of a susceptible cultivar (Early Wataribune). Nira sustained 15% more small larvae than Early Wataribune whereas numbers of medium and large larvae were much reduced in Nira compared with Wataribune. Their results indicated that the mechanism of resistance in Nira was antibiosis. In this study, the mechanism of resistance in lines 244 and 2232 appeared to be antixenosis since larval
development was not affected by plant resistance characteristics. Smith and Robinson (1982) also identified four other cultivars (Bondoc, Carangiang, Dawn, Finidoc) as resistant to the rice water weevil with low larval populations, but with no indication of antibiotic activity. Larval populations associated with a particular line may reflect the number of eggs laid, indicating nonpreference or preference of the host plant for adult oviposition. Because egg data were not recorded in this study to rule out the possibility of ovicidal antibiosis, further studies are needed to elucidate the mechanism of resistance in lines 244 and 2232.

Lines 67, 93, 112, 120, 244 and 2232 were all regenerated from tissue culture of the susceptible cultivar, Tebonnet. These tissue culture derived lines proved to be resistant to the rice water weevil in the preliminary study in 1990 when compared with the parent Tebonnet. In subsequent tests, although Tebonnet was not used as a check, lines 244 and 2232 demonstrated antixenotic resistance and line 112 demonstrated tolerance to the rice water weevil compared with Mars. This suggests that tissue culture may be an effective and a more rapid means of developing rice cultivars for insect and disease resistance. Similar results have been obtained by Croughan and Quisenberry (1989) who found that level of resistance in bermudagrass to fall armyworm, Spodoptera frugiperda (J. E. Smith), was increased through tissue culture. White and
Irvine (1987) found that sugarcane plants regenerated from a cultivar susceptible to the sugarcane borer, *Diatraea saccharalis* (F.), exhibited variable levels of borer resistance.

Lines 244 and 2232, which exhibited antixenotic resistance to the rice water weevil, had lower yield potential than the susceptible commercial cultivar, Mars, in the preliminary study in 1990. Thus, these lines should be crossed with high yielding commercial rice cultivars in a breeding program to incorporate the rice water weevil resistance into new cultivars. Line 4754 had higher yield potential than the commercial cultivar, Mars, and also was slightly shorter than Mars, suggesting that it is not susceptible to lodging. Although other agronomic characteristics were not considered in this study, the plant height and grain type of line 4754 indicates that it has potential for use as a commercial cultivar.

Considering the characteristics of the lines evaluated in this study, both lines 112 and 4754 may be crossed with either line 244 or 2232 to combine antixenosis, tolerance and high yield potential into a new cultivar.
References - Chapter II


(Coleoptera: Curculionidae) in California. J. Econ. Entomol. 85(3): 950-956.


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.


Latson, L. N. and G. B. Trahan. 1977. Host plant resistance to the rice water weevil, pp. 113-139. In Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station, vol. 69, Crowley.


N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening tissue culture lines for resistance to the rice water weevil, pp. 324-325. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990c. Screening rice lines for resistance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


Robinson, J. F., C. M. Smith, and G. B. Trahan. 1980a. Rice water weevil: water management as a cultural control method, pp. 204-211. In 72nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.


CHAPTER III

SCREENING SELECTED RICE LINES FOR RESISTANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)
Rice, *Oryza sativa* L., is attacked by several insect species. Among these, the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, represents the most severe insect pest in the rice-growing areas of the United States and recently Japan and Korea (Newsom and Swanson 1962, Hirao 1978). Both the larvae and the adult attack the rice plant. Adult feeding damage to the foliage is generally of little importance, although Ingram (1927) reported plantlet death due to adult feeding in some late planted fields. Larval root feeding is considered the greatest source of damage, since larvae can prune almost all of the roots from the plant. Root pruning stunts the growth of young plants and causes yield loss at maturity (Newsom and Swanson 1962, Bowling 1967a). Several researchers, including Tucker (1912), Bowling (1957), Rolston and Rouse (1960) and Grigarick (1963), have reported yield losses ranging from 1% to 75%.

Early rice water weevil control efforts consisted of draining rice fields to reduce larval root pruning (Isely and Schwardt 1934). However, subsequent research efforts by Robinson et al. (1980a), Morgan et al. (1989) and Hesler et al. (1992) indicated that this practice is impractical due to fertilizer loss and ineffectiveness in larval control when the field is reflooded too soon. Consequently, insecticides have been the primary means of rice water weevil control (Bowling 1957, 1967b; Rolston and

Recent research on water management indicated that draining rice fields under specific conditions and on specific dates can provide effective and economic control of the rice water weevil (Quisenberry et al. 1992). Nevertheless, there still exists an urgent need to develop additional rice water weevil control tactics that could be used in an integrated management approach.

Host plant resistance is a potential alternative as well as an addition to chemical and other control tactics of the rice water weevil. Several researchers (Bowling 1963; Gifford et al. 1973; Gifford and Trahan 1975; Robinson et al. 1978, 1979, 1980b, 1981, 1982); Smith et al. 1979; Smith and Robinson 1982; and N'Guessan et al. 1990a, 1990b, 1990c, 1990d) have investigated rice water weevil resistance in rice; however, limited progress has been made. Only a few exotic rice genotypes with moderate tolerance have been identified in California by Grigarick et al. (1976) and in Louisiana by Gifford and Trahan (1975). Smith and Robinson (1982) reported five cultivars of Philippine origin to be moderately resistant to the rice water weevil larval infestation, adult feeding, or both.

Plant resistance can be manifested as antixenosis (the plant acts as a poor host and the insect pest selects an alternate host plant), antibiosis (the biology of the insect pest is adversely affected), or tolerance (the plant
simply withstands or recovers from insect damage and produces normal yield) (Smith 1989). Any of these modalities of resistance is important in the development of resistant cultivars. The initial step in the development of rice cultivars resistant to rice water weevil is to identify rice water weevil resistant germplasm. The objective of this study was to identify rice germplasm with antibiosis, antixenosis and/or tolerance to the rice water weevil in selected rice germplasm.

Materials and Methods

Preliminary field screening of 50 rice lines of various origin in 1990 for resistance to the rice water weevil yielded several cultivars with potential for resistance. The best of these cultivars were further evaluated in 1991 and 1992 to confirm their resistance to the rice water weevil. Lines selected from the 1990 test were separated in two groups: one group was tested specifically for tolerance and the other was tested for antixenosis and/or antibiosis.

Tolerance Test. Twenty-two lines were initially selected from the 1990 preliminary test. However, following the 1991 advanced test, the number of lines was reduced to 12 (858, 859, 860, 861, AL6029, AL11469, LA2218, TX22041, URN51, URN64, URN199, URN200) for final evaluation in 1992. Research was conducted under field conditions at the Rice Research Station, Crowley, LA. The experimental design was a randomized block with six replicates in 1991.
In 1992, two plantings (Trial 1 and 2) were made in two different sites (Crowley silt loam for trial 1 and Midland silt loam for trial 2). A split-plot with six replicates was used in 1992 for both trials to better assess tolerance. Mars and WC1403 were used in each replicate as susceptible and tolerant controls, respectively, during both years. For the split plot, the treatments (rice lines) were planted in paired plots (one treated with insecticide, the other not treated) within each replicate. Thus, the whole plots were the different rice lines and the sub-plots were two levels (treated, untreated) of insecticide. The cultivars were drill seeded (3 g/row) on 5 June 1991 and 19 May 1992 for Trial 1, and 17 June 1992 for Trial 2. Plot size was six 2-meter rows (2 by 1.22 m), spaced 0.9 m between strips and 0.5 m within strips. Row spacing was 0.25 m. Propanil herbicide (4.5 kg [AI]/ha; Rohm & Haas Company, Philadelphia, Pa.) was applied to all plots on 19 June 1991. In 1992, herbicide was applied on 9 June 1992 for Trial 1, and 23 June and 6 July 1992 for Trial 2. Before permanent flooding, established on 20 June 1991, and 12 June 1992 for trial 1 and 8 July 1992 for Trial 2; fertilizer (134:67:67 kg [AI]/ha of N P K) was also applied to all plots on 20 June 1991, and 11 June 1992 for Trial 1 and 7 July 1992 for Trial 2. Carbofuran (FMC, Philadelphia, Pa.) at 1.12 kg [AI]/ha was applied with a shaker jar on 18 and 26 June 1992 for trial 1, and 20 and 27 July 1992 for Trial 2.
Twenty-one d after permanent flood, three soil-root core samples (9.2 cm diam. by 7.6 cm deep) were taken from each plot and individually bagged in prelabeled bags to assess rice water weevil larval population. The soil was washed off the roots of the plants through a 40-mesh copper sieve. The residue was placed in a saturated sodium chloride solution and the floating rice water weevil larvae and pupae were counted. Root damage was assessed with a visual rating of the root system at 28 and 35 d postflood in 1991 and at 28, 35 and 42 d in trial 1 in 1992. Rice samples (three plants/plot) were pulled from each plot, the soil was washed off the roots and a score was given to the root system using a 0 to 5 scale; where, 0 = no root damage, 1 = about 1/3 of root system pruned with some root regrowth, 2 = about 1/3 of root system pruned with no regrowth, 3 = about 2/3 of root system pruned with some root regrowth, 4 = entire root system pruned with some root regrowth and 5 = entire root system damaged with no regrowth.

At maturity, before harvest, a representative height (three plants/plot) was measured at random from each plot to assess the difference in growth between the treated and untreated plots. Plots were harvested (1 October 1991 and, 11 September 1992 for Trial 1 and 28 October 1992 for trial 2) and the grain yield was determined to assess loss due to root pruning damage. The 1992 data were used to calculate percent height (% Ht diff) and percent yield (% Yd diff)
differences as follows: \( \% \text{ Ht diff} = ([\text{treated Ht} - \text{untreated Ht}] / \text{treated Ht}) \times 100; \% \text{ Yd diff} = ([\text{treated Yd} - \text{untreated Yd}] / \text{treated Yd}) \times 100. \)

The data were subjected to analysis of variance (ANOVA) using SAS General Linear Model Procedure (SAS Institute 1985). The means were separated using Tukey's Studentized Range (HSD) test. A paired T test (Proc means, percent difference) was used to compare the treated and untreated variables. Root damage ratings were analyzed as a split-split-plot in which sampling date was the sub-sub-plot.

Antixenosis Test. Nine lines (8936825, Gulfmont, URN141, URN166, URN175, TX12630, TX12685, TX13079, WC502805) were selected for this test based on low rice water weevil larval population levels in the preliminary field screening in 1990. In 1991 and 1992, randomized block experiments with 5 replicates were conducted in the field. The nine lines and two susceptible check cultivars (Lemont, Mars) were drill seeded (17 June 1991 and 19 May 1992). Plots were single 2-m rows, spaced 0.9 m apart with 0.25 m row spacing. Other agricultural practices were similar to that of the tolerance test. Permanent flood was established on 2 July 1991 and 12 June 1992, propanil was applied on 29 June 1991 and 9 June 1992 and fertilizer was applied 1 July 1991 and 11 June 1992. Three core samples were taken from each plot and processed in a similar manner as the above tolerance experiment. All data were analyzed
as randomized block design using SAS General Linear Model Procedure (SAS Institute 1985). The means were separated using Tukey's Studentized Range (HSD) test.

Results and Discussion

Tolerance Test. The degree of plant resistance is based on comparison to susceptible plants that are more severely damaged under similar test conditions. Tolerance is determined by comparing the production of plant biomass (e.g., yield) in insect-infested and noninfested plants of the same cultivar (Smith 1989). In this study, tolerance was determined by comparing yields in insecticide treated and untreated plots.

In 1991, larval populations differed significantly (df = 21,105; $F = 4.67, P < 0.0001$) among the lines evaluated (Table 3.1). In 1992, the infestation level in trial 1 was twice that in trial 2, and differences in larval populations were not significant in trial 1 but were significant in trial 2 (df = 13,65; $F = 2.95, P < 0.002$) (Table 3.2). Insecticide effect was significant in trial 1 (df = 1,5; $F = 60.62, P < 0.0006$) and trial 2 (df = 1,5; $F = 137.9, P < 0.0001$). There was no line by insecticide interaction in either trial. In addition, none of the test lines had significantly lower larval populations than the susceptible check (Mars) in the untreated plot, indicating that larval antibiosis is questionable in the lines evaluated. Larval populations in the treated plots ranged from 6 to 10.5 larvae/core compared with 31 to 45.2
Table 3.1. Mean number of rice water weevil larvae per core and yield of selected rice lines evaluated for tolerance, Crowley, La., 1991

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Larvae/core</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>858</td>
<td>27.1 ± 2.5a-d</td>
<td>4472.8 ± 320.3b-f</td>
</tr>
<tr>
<td>859</td>
<td>25.9 ± 2.2a-d</td>
<td>4087.9 ± 195.6d-g</td>
</tr>
<tr>
<td>860</td>
<td>32.1 ± 3.0a-d</td>
<td>3986.0 ± 290.1d-g</td>
</tr>
<tr>
<td>861</td>
<td>31.3 ± 4.0a-d</td>
<td>4115.4 ± 408.4b-g</td>
</tr>
<tr>
<td>AL2541</td>
<td>36.2 ± 1.0ab</td>
<td>-</td>
</tr>
<tr>
<td>AL6029</td>
<td>39.3 ± 4.4a</td>
<td>5354.6 ± 109.1b</td>
</tr>
<tr>
<td>AL11469</td>
<td>32.2 ± 3.2a-d</td>
<td>7977.2 ± 184.1a</td>
</tr>
<tr>
<td>LA2218</td>
<td>34.5 ± 2.3a-c</td>
<td>4794.0 ± 148.6bcd</td>
</tr>
<tr>
<td>TX22041</td>
<td>23.0 ± 2.8b-d</td>
<td>3954.8 ± 154.4efg</td>
</tr>
<tr>
<td>TX22042</td>
<td>20.8 ± 0.7cd</td>
<td>3522.1 ± 350.9efg</td>
</tr>
<tr>
<td>URN6</td>
<td>18.3 ± 1.8d</td>
<td>3478.8 ± 246.0efg</td>
</tr>
<tr>
<td>URN45</td>
<td>21.5 ± 1.5cd</td>
<td>3425.6 ± 255.5fg</td>
</tr>
<tr>
<td>URN51</td>
<td>32.3 ± 3.9a-d</td>
<td>4554.7 ± 316.4b-e</td>
</tr>
<tr>
<td>URN64</td>
<td>19.7 ± 2.7d</td>
<td>3846.4 ± 369.0efg</td>
</tr>
<tr>
<td>URN96</td>
<td>21.1 ± 1.1cd</td>
<td>2739.7 ± 418.8g</td>
</tr>
<tr>
<td>URN199</td>
<td>32.3 ± 4.9a-d</td>
<td>6864.4 ± 245.5a</td>
</tr>
<tr>
<td>URN200</td>
<td>27.3 ± 4.5a-d</td>
<td>5324.3 ± 105.7bc</td>
</tr>
<tr>
<td>WC376224</td>
<td>30.2 ± 4.1a-d</td>
<td>-</td>
</tr>
<tr>
<td>LEMONT</td>
<td>22.6 ± 1.0b-d</td>
<td>3631.2 ± 331.8efg</td>
</tr>
<tr>
<td>MARS</td>
<td>36.0 ± 3.4ab</td>
<td>3508.3 ± 224.3efg</td>
</tr>
<tr>
<td>WC1403</td>
<td>27.5 ± 3.1a-d</td>
<td>3413.5 ± 147.1fg</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
Table 3.2. Mean number of rice water weevil larvae per core in selected rice lines evaluated for tolerance, Crowley, La., 1992 (Trials 1&2)

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Trial 1</th>
<th>Treated</th>
<th>Untreated</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>858</td>
<td>45.2 ± 5.7a</td>
<td>10.5 ± 2.7a</td>
<td>18.8 ± 2.4a</td>
<td>1.6 ± 0.5a</td>
</tr>
<tr>
<td>859</td>
<td>43.7 ± 4.4a</td>
<td>8.7 ± 1.1a</td>
<td>15.6 ± 1.2ab</td>
<td>1.4 ± 0.5a</td>
</tr>
<tr>
<td>860</td>
<td>42.3 ± 4.8a</td>
<td>8.1 ± 2.4a</td>
<td>13.2 ± 0.8ab</td>
<td>1.6 ± 0.9a</td>
</tr>
<tr>
<td>861</td>
<td>37.6 ± 4.1a</td>
<td>8.7 ± 3.2a</td>
<td>15.3 ± 3.4ab</td>
<td>1.0 ± 0.2a</td>
</tr>
<tr>
<td>AL6029</td>
<td>44.5 ± 4.2a</td>
<td>7.8 ± 1.8a</td>
<td>14.7 ± 2.1ab</td>
<td>1.9 ± 0.9a</td>
</tr>
<tr>
<td>AL11469</td>
<td>34.1 ± 3.2a</td>
<td>6.4 ± 2.2a</td>
<td>15.0 ± 1.2ab</td>
<td>0.6 ± 0.3a</td>
</tr>
<tr>
<td>LA2218</td>
<td>44.2 ± 4.2a</td>
<td>9.1 ± 3.3a</td>
<td>19.7 ± 2.0a</td>
<td>2.0 ± 0.5a</td>
</tr>
<tr>
<td>TX22041</td>
<td>41.6 ± 5.9a</td>
<td>7.8 ± 3.0a</td>
<td>9.7 ± 1.5b</td>
<td>1.6 ± 0.8a</td>
</tr>
<tr>
<td>URN51</td>
<td>36.8 ± 3.4a</td>
<td>5.5 ± 1.1a</td>
<td>15.1 ± 0.9ab</td>
<td>0.8 ± 0.2a</td>
</tr>
<tr>
<td>URN64</td>
<td>44.5 ± 4.7a</td>
<td>8.7 ± 3.4a</td>
<td>12.9 ± 2.3ab</td>
<td>0.7 ± 0.2a</td>
</tr>
<tr>
<td>URN199</td>
<td>43.3 ± 2.5a</td>
<td>6.9 ± 1.7a</td>
<td>16.9 ± 2.9ab</td>
<td>3.5 ± 1.1a</td>
</tr>
<tr>
<td>URN200</td>
<td>31.0 ± 4.6a</td>
<td>7.1 ± 1.8a</td>
<td>14.2 ± 0.9ab</td>
<td>3.0 ± 0.9a</td>
</tr>
<tr>
<td>MARS</td>
<td>39.6 ± 9.8a</td>
<td>7.4 ± 3.1a</td>
<td>17.8 ± 1.7ab</td>
<td>1.5 ± 0.2a</td>
</tr>
<tr>
<td>WC1403</td>
<td>37.8 ± 7.0a</td>
<td>6.0 ± 3.0a</td>
<td>15.0 ± 2.8ab</td>
<td>1.3 ± 0.4a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
larvae/core in the untreated plots for trial 1, and 0.6 to 3.5 larvae/core compared with 9.7 to 19.7 larvae/core for trial 2 in 1992 (Table 3.2).

Root damage ratings in the untreated plots at different dates are shown in Figs. 3.1 and 3.2 in 1991 and 1992, respectively. There was no interaction between line and insecticide for root ratings, but there was a significant (df = 26,280; F = 2.7, P < 0.0001) line by sampling date interaction, indicating that variation in root biomass over time was not the same for all the lines evaluated. Root damage ratings were relatively high for most of the lines at 28 d of permanent flood in 1991 and 1992. However, there was an overall decrease in root damage ratings for lines 858, 861, AL6029, TX22041, URN51, URN199 and URN200 at 35 and 42 d postflood in 1992, suggesting that these lines were recovering from root damage. Recovery from root damage was not evident in 1991 because root damage rating was performed only on two dates (Fig. 3.1). Root damage ratings in the treated plots ranged from 1 to 1.5 compared with 3 to 4.5 in the untreated plots (Figs. 3.2 and 3.3), indicating that the carbofuran treatment was effective in reducing root pruning in the treated plots.

Tables 3.3 and 3.4 show height and yield data for 1992 (trials 1 and 2). There were significant (P < 0.05) line by insecticide interactions for grain yield and plant height in both trials, suggesting that yield and height
Fig. 3.1. Root damage ratings at 28 and 35 d postflood of plants in untreated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La. 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 3.2. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La. 1992. Bars with the same letters within lines indicates means are not significantly different (P > 0.05), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 3.3. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
ROOT DAMAGE RATING

28 d POSTFLOOD
35 d POSTFLOOD
42 d POSTFLOOD

CULTIVAR/LINE

858  859  860  861  AL6029  AL11469  LA2218  TX22041  URN51  URN64  URN199  URN200  MARS  WC1403
Table 3.3. Height and yield of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 (Trial 1)

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>858</td>
<td>91.3</td>
<td>85.1</td>
</tr>
<tr>
<td>859</td>
<td>85.8</td>
<td>80.7</td>
</tr>
<tr>
<td>860</td>
<td>87.9</td>
<td>82.7</td>
</tr>
<tr>
<td>861</td>
<td>94.1</td>
<td>89.8</td>
</tr>
<tr>
<td>AL6029</td>
<td>170.9</td>
<td>164.6</td>
</tr>
<tr>
<td>AL11469</td>
<td>140.4</td>
<td>137.2</td>
</tr>
<tr>
<td>LA2218</td>
<td>94.8</td>
<td>89.1</td>
</tr>
<tr>
<td>TX22041</td>
<td>104.5</td>
<td>98.3</td>
</tr>
<tr>
<td>URN51</td>
<td>95.1</td>
<td>89.2</td>
</tr>
<tr>
<td>URN64</td>
<td>100.5</td>
<td>93.9</td>
</tr>
<tr>
<td>URN199</td>
<td>100.9</td>
<td>99.1</td>
</tr>
<tr>
<td>URN200</td>
<td>112.5</td>
<td>107.3</td>
</tr>
<tr>
<td>MARS</td>
<td>114.5</td>
<td>107.7</td>
</tr>
<tr>
<td>WC1403</td>
<td>130.9</td>
<td>123.5</td>
</tr>
</tbody>
</table>

¹ % Ht diff = ([treated height - untreated height]/treated height) * 100.
* Indicates significant at P < 0.05 (Paired T test).
Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
Table 3.4. Height and yield of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 (Trial 2)

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>858</td>
<td>75.44</td>
<td>73.11</td>
</tr>
<tr>
<td>859</td>
<td>76.00</td>
<td>72.88</td>
</tr>
<tr>
<td>860</td>
<td>74.88</td>
<td>73.11</td>
</tr>
<tr>
<td>861</td>
<td>80.00</td>
<td>77.67</td>
</tr>
<tr>
<td>AL6029</td>
<td>146.33</td>
<td>137.00</td>
</tr>
<tr>
<td>AL11469</td>
<td>115.33</td>
<td>112.44</td>
</tr>
<tr>
<td>LA2218</td>
<td>85.22</td>
<td>78.22</td>
</tr>
<tr>
<td>TX22041</td>
<td>96.33</td>
<td>91.88</td>
</tr>
<tr>
<td>URN51</td>
<td>89.88</td>
<td>84.00</td>
</tr>
<tr>
<td>URN64</td>
<td>95.77</td>
<td>92.33</td>
</tr>
<tr>
<td>URN199</td>
<td>92.77</td>
<td>90.77</td>
</tr>
<tr>
<td>URN200</td>
<td>103.22</td>
<td>98.00</td>
</tr>
<tr>
<td>MARS</td>
<td>99.00</td>
<td>98.11</td>
</tr>
<tr>
<td>WC1403</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>1</sup> % Ht diff = ([treated height - untreated height]/treated height) * 100.
* Indicates significant at P < 0.05 (Paired T test).
Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
response to carbofuran treatment differed among the lines evaluated. Several lines did not show significant height and yield differences between treated and untreated plots. Some of the lines evaluated in this study were too tall and therefore susceptible to lodging. Overall, plants in the treated plots were taller than plants in the untreated plots.

The significant height differences between plants in the treated and untreated plots, in some lines, can be attributed to the heavier larval root pruning in the untreated plots than in the treated plots as reflected in root rating data. However, Venugopal (1981) reported that carbofuran can influence plant growth and that its effect is variable and cultivar dependant. Thus, the carbofuran treatment may have contributed to height differences. Nevertheless, lines 859, 860, AL6029, URN200 and the susceptible check (Mars) that showed significant height differences between treated and untreated plots in the first trial did not show significant height differences between treated and untreated plots in the second trial in 1992 (Tables 3.3 and 3.4). Thus, stunting of plant in the untreated plots was primarily caused by rice water weevil larval root pruning.

Differences in grain yield among the lines tested were highly significant (df = 19,79; F = 31.38; P < 0.0001) in 1991 (Table 3.1). In 1992, yield differences among lines were also significant in trial 1 (df = 13,62; F = 44.28; P
< 0.0001) and trial 2 (df = 13,61; F = 19.47; P < 0.0001) (Tables 3.3 and 3.4). Although the rice water weevil infestation level was higher in trial 1 than trial 2, yield overall was higher in trial 1 than trial 2. This difference may be attributed to difference in soil type. The moderately tolerant check (WC1403) did not show significant yield loss when not treated with insecticide in both trials, but yielded less than the susceptible check (Mars) in trial 1.

Several lines, including URN199, URN200, A16029, A11469, La2218, 858, 859, and 860, averaged higher yields than the susceptible check cultivar (Mars) in 1991 and 1992. When yield differences between treated and untreated plots were assessed for individual lines in 1992 (Figs. 3.4 and 3.5), lines A16029, LA2218, TX22041, URN199 and URN200 did not show significant differences in both trials. This suggests that these lines are tolerant to the insect. Yield differences between treated and untreated plots were also lowest in these lines (Figs. 3.4 and 3.5).

Gifford and Trahan (1975), Grigarick (1974), and Latson and Trahan (1977) suggested that root damage recovery or total root biomass contributed to rice water weevil resistance in rice. In this study, although root damage ratings data in 1991 did not provide an accurate indication of root recovery, data in 1992 indicated that lines A16029, TX22041, URN199 and URN200 recovered from root pruning damage. This explains, in part, their ability
Fig. 3.4. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of selected rice lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992 (Trial 1). Bars with * indicates that yield loss is significant. Paired T test results were: 858, $T = 5.8$, $P < 0.002$; 859, $T = 7.2$, $P < 0.0008$; 860, $T = 4.4$, $P < 0.006$; 861, $T = 4.8$, $P < 0.004$; AL6029, $T = 2.4$, $P > 0.07$; AL11469, $T = 4.3$, $P < 0.007$; LA2218, $T = 1.8$, $P > 0.12$; TX22041, $T = 2.2$, $P > 0.08$; URN51, $T = 6.5$, $P < 0.001$; URN64, $T = 2.7$, $P < 0.04$; URN199, $T = 2.4$, $P > 0.06$; URN200, $T = 1.9$, $P > 0.12$; Mars, $T = 5.0$, $P < 0.004$; WC1403, $T = 2.4$, $P > 0.13$. 
CULTIVAR/LINE

PERCENT YIELD LOSS

0  5  10  15  20  25  30

858  *  
859  *  
860  *  
861  *  
AL6029 NS  
AL11469 *  
LA2218 NS  
TX22041 NS  
URN51  *  
URN64  *  
URN199 NS  
URN200 NS  
MARS  *  
WC1403 NS  

IT
Fig. 3.5. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of selected rice lines evaluated for resistance to the rice water weevil, Crowley, La., 1992 (Trial 2). Bars with * indicates that yield loss is significant. Paired T test results were: 858, $T = 8.9, P < 0.0003$; 859, $T = 4.2, P < 0.008$; 860, $T = 3.3, P < 0.01$; 861, $T = 6.5, P < 0.001$; AL6029, $T = 2.2, P > 0.09$; AL11469, $T = 1.9, P > 0.11$; LA2218, $T = 1.7, P > 0.14$; TX22041, $T = 1.5, P > 0.18$; URN51, $T = 6.7, P < 0.001$; URN64, $T = 3.1, P < 0.04$; URN199, $T = 1.8, P > 0.12$; URN200, $T = 2.4, P > 0.06$; Mars, $T = 6.9, P < 0.001$; WC1403, $T = 1.1, P > 0.36$. 
PERCENT YIELD LOSS

CULTIVAR/LINE

858
859
860
861
AL6029
AL11469
LA2218
TX22041
URN51
URN64
URN199
URN200
MARS
WC1403

NS
NS
NS
NS
NS
NS
NS
NS
NS
NS
NS
NS
NS
to produce high yields in the untreated plots despite sustaining high rice water weevil larval populations. In the untreated plots, plants of a cultivar with a high potential for root recovery may be able to recover from damage faster and produce more tillers compared with a cultivar with little or no potential for root recovery. Ho et al. (1982) found that rice tolerance to planthoppers was expressed as the ability of tolerant cultivars to survive and produce higher percentage of productive tillers than the susceptible cultivars.

Antixenosis Test. Results from the antixenosis test indicated that larval populations differed significantly in 1991 ([df=10,39], 21 d postflood, $F = 4.85, P < 0.0001$; 28 d postflood, $F = 4.79, P < 0.0001$) and 1992 (df=10,39; $F = 11.9, P < 0.0001$) among the lines evaluated (Table 3.5). Two lines (TX12685, TX13079) sustained significantly lower larval populations than the susceptible check, Mars, during both years, indicating that they are resistant to the rice water weevil.

The number of larvae in each size category were compared to determine whether the mechanism of resistance is antibiosis or antixenosis (Figs. 3.6 and 3.7). A cultivar averaging high populations of small larvae, reduced number of medium and little or no large larvae at 21 and 28 d of permanent flooding would be suspected to have antibiotic activity. This method was previously used by Smith and Robinson (1982) who suggested that cultivar
Table 3.5. Mean number of rice water weevil larvae per core in selected rice lines evaluated for antixenosis/antibiosis, Crowley, La., 1991-1992

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8936825</td>
<td>15.4 ± 1.9ab</td>
<td>32.4 ± 6.6ab</td>
<td>49.9 ± 4.2a</td>
</tr>
<tr>
<td>Gulmont</td>
<td>18.9 ± 3.1ab</td>
<td>16.9 ± 3.1c</td>
<td>43.0 ± 2.8a</td>
</tr>
<tr>
<td>TX12630</td>
<td>17.0 ± 2.5ab</td>
<td>18.3 ± 1.7bc</td>
<td>23.8 ± 1.7b</td>
</tr>
<tr>
<td>TX12685</td>
<td>10.0 ± 1.8b</td>
<td>12.2 ± 1.9c</td>
<td>23.4 ± 1.4b</td>
</tr>
<tr>
<td>TX13079</td>
<td>11.0 ± 1.2b</td>
<td>15.4 ± 2.4c</td>
<td>21.4 ± 1.8b</td>
</tr>
<tr>
<td>URN141</td>
<td>16.1 ± 3.3ab</td>
<td>20.7 ± 2.6abc</td>
<td>38.3 ± 3.1a</td>
</tr>
<tr>
<td>URN166</td>
<td>14.6 ± 3.2ab</td>
<td>25.8 ± 2.3abc</td>
<td>46.1 ± 5.8a</td>
</tr>
<tr>
<td>URN175</td>
<td>16.5 ± 2.3a</td>
<td>22.5 ± 3.7abc</td>
<td>42.2 ± 2.5a</td>
</tr>
<tr>
<td>WC502805</td>
<td>21.4 ± 3.9ab</td>
<td>22.0 ± 2.9abc</td>
<td>42.8 ± 2.3a</td>
</tr>
<tr>
<td>LEMONT</td>
<td>12.8 ± 2.0b</td>
<td>15.6 ± 2.5c</td>
<td>43.2 ± 3.0a</td>
</tr>
<tr>
<td>MARS</td>
<td>28.6 ± 4.9a</td>
<td>32.7 ± 3.7a</td>
<td>49.5 ± 2.7a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]). Analysis of variance results were: 1991, (df=10,39); 21 d postflood, F = 4.85, P < 0.0001; 28 d postflood, F = 4.79, P < 0.0001; 1992, (df=10,39), F = 11.9, P < 0.0001.
Fig. 3.6. Rice water weevil larval populations in different size categories for selected rice lines evaluated for resistance, Crowley, La., 1991: A. 21 d postflood; B. 28 d postflood.
RICE WATER WEEVIL/CORE

A.  B.

CULTIVAR/LINE

RICE WATER WEEVIL/CORE

TX12685  TX13079  MARS  TX12685  TX13079  MARS

SMALL  MEDIUM  LARGE

0  2  4  6  8  10  12  14  16
Fig. 3.7. Rice water weevil larval populations in different size categories for selected rice lines evaluated for resistance, Crowley, La., 1992.
Nira may possess a growth inhibiting factor that could have reduced rice water weevil larval growth. In this study, lines TX12685 and TX13079, which showed resistance to the rice water weevil, have more large than small and medium larvae, indicating that larval growth is normal in these lines. Thus, the mechanism of resistance appeared to be antixenosis. The low larval populations associated with lines TX12685 and TX13079 may be attributed to nonpreference for adult oviposition rather than larval mortality. However, because preference or nonpreference for adult oviposition was not assessed in this study, further studies are needed to elucidate the mechanism of resistance in lines TX12685 and TX13079.

The infestation in 1992 was twice that in 1991, but the trend in larval population was relatively consistent in both years. Lemont (susceptible check) averaged low numbers of rice water weevil larvae in 1991, but sustained high larval population in 1992 (Table 3.5). Lines TX12685 and TX13079 averaged twice as many larvae in 1992 than in 1991, indicating that level of infestation in these lines increased as the general level of infestation in the field increased. Based on the data from this study, TX12685 and TX13079 may sustain high rice water weevil larval populations and damage if either one is planted in the absence of a more susceptible line.

Insect resistance has played a very important role in the management of insect pests of rice. In many Asian
countries where planthoppers and leafhoppers have become difficult to control with insecticides, growers have successfully used resistant cultivars (Heinrichs et al. 1985). Smith (1989) stated that in some instances, high levels of resistance can be detrimental to both pest insects (development of biotypes) and beneficial insects (mortality). Thus, crops with moderate levels of resistance should be considered for use in IPM systems. The levels of resistance found in this study are moderate, but can be useful in an integrated management approach.

Among the lines that exhibited tolerance to the rice water weevil, LA2218, URN199 and URN200 were selected from the uniform regional rice nursery in 1990 and thus, may be released as commercial cultivars in the near future. Lines AL6029 and TX22041 do not have good agronomic characteristics but may be used as resistant germplasms in a breeding program to incorporate tolerance into commercially acceptable lines. Gifford and Trahan (1976) reported that 25% of F2 generation plants, from a cross between a moderately tolerant line and a commercial cultivar, displayed outstanding root regrowth, indicating that tolerance can be incorporated to produce a new resistant cultivar.
References - Chapter III


Bowling, C. C. 1967b. Test with insecticides as seed treatments to control rice water weevil. J. Econ. Entomol. 60: 18-19.


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.


Latson, L. N. and G. B. Trahan. 1977. Host plant resistance to the rice water weevil, pp 113-139. In 69th Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.


N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening tissue culture lines for resistance to the rice water weevil, pp. 324-325. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990c. Screening rice lines for resistance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.
N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990d. Screening rice breeding lines for tolerance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


Tucker, E. S. 1912. The rice water weevil and methods for its control. USDA Bureau Entomol. Circular 152.

CHAPTER IV

EVALUATION OF RICE ANther CULTURE LINES FOR TOLERANCE TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)
The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most destructive insect pest of rice (*Oryza sativa* L.) in many rice-growing areas of the United States, including Louisiana (Newsom and Swanson 1962). This insect was recently introduced to Japan and Korea where it has become a serious pest and poses a threat to rice production in Asia (Hirao 1978). Adult weevils attack the leaves and leave distinctive longitudinal slit-like scars; however, leaf feeding damage is usually of minor importance because the young plant recovers from the damage (Ingram 1927). Economic damage is caused by the larval pruning of the root system which results in stunting of younger plants and lodging and yield reduction in mature plants (Isely and Schwardt 1934, Bowling 1967). Newsom and Swanson (1962) reported rough rice yield loss of up to 1120 kg/ha.

Insecticides are the main control tactic for management of the rice water weevil on rice, but research is underway to develop alternative methods. Plant resistance is a potential alternative or an adjunct to other control tactics in an integrated control program. However, identification of sources of rice water weevil resistance has been difficult. Thousands of rice lines have been screened (Gifford et al. 1973; Gifford and Trahan 1975; Grigarick et al. 1976; Robinson et al. 1978, 1979, 1980, 1981, 1982; Smith et al. 1979; Smith and Robinson 1982 and N'Guessan et al. 1990a, 1990b, 1990c, 1990d. However, only a few exotic rice genotypes with moderate
tolerance to the rice water weevil larval feeding have been identified in California by Grigarick et al. (1976) and in Louisiana by Gifford and Trahan (1975) and Smith and Robinson (1982).

Recently, biotechnology has offered a number of new approaches to facilitate rice breeding for insect and disease resistance. Anther culture is a technique used to regenerate plants with differing characteristics from the culture of anthers within immature panicles (Croughan and Robinson 1990, Chu and Croughan 1990). Plants produced with this technique frequently differ genetically from the original donor plant (Croughan and Robinson 1990). Croughan and Robinson (1990) stated that mutations frequently induced in rice through this procedure include changes in plant height, days to maturity, tillering, leaf shape and display, grain size, panicle size, degree of sterility, and insect and/or disease resistance. A number of new rice lines have been regenerated from laboratory-cultured anthers in China and in the United States (Croughan and Robinson 1990). However, no information exists on these lines with regard to insect resistance. The present study was initiated to investigate rice water weevil resistance in rice regenerated from anther culture.

Materials and Methods

Preliminary field screening of 43 rice anther culture lines in 1990 for resistance to the rice water weevil yielded several lines with potential for tolerance. The
seven most promising lines (952836, 953508, 953509, 953510, 953511, 953527, 953541) were further evaluated in 1991 and 1992.

Research was conducted under field conditions at the Rice Research Station near Crowley, Louisiana. The experimental design was a split-plot with six replicates. Within each replicate, each treatment (rice line) was divided into two units organized in strips, one treated with insecticide and the other not treated. The cultivars were drill seeded (3 g/row) on 17 June 1991 and 8 May 1992. Plot size was six 2-meter rows (2 by 1.22 m), spaced 0.9 m between strips and 0.5 m within strips with a 0.25 m row spacing. A susceptible cultivar (Mars) and a moderately tolerant world collection line (WC1403) were used as checks in each replicate. Propanil (4.5 kg [AI]/ha; Rohm & Haas Company, Philadelphia, Pa.) herbicide was applied to all plots on 29 June 1991 and 1 June 1992. Before permanent flood (2 July 1991 and 5 June 1992), fertilizer (134:67:67 kg [AI]/ha of N P K) was also applied to all plots (1 July 1991 and 4 June 1992). Carbofuran (FMC, Philadelphia, Pa.) at 1.12 kg [AI]/ha was applied to the treated units with a shaker jar on 3 and 7 July 1991, and 8 and 18 June 1992.

Twenty-one d after permanent flood, three soil-root core samples (9.2 cm diam. by 7.6 cm deep) were taken from each plot and individually bagged in prelabeled bags to assess rice water weevil larval population. The soil was washed off the roots of the plants through a 40-mesh copper
sieve. The residue was placed in a saturated sodium chloride solution and floating rice water weevil larvae and pupae were counted. Root damage was assessed through a visual rating of the root system. Three plants were randomly pulled from each plot, the soil was washed off the roots and a root damage score was given to the root system using a 0 to 5 scale; where, 0 = no root damage, 1 = about 1/3 of root system pruned with root regrowth, 2 = about 1/3 of root system pruned with no regrowth, 3 = about 2/3 of root system pruned and some regrowth, 4 = entire root system pruned with some regrowth of new roots and 5 = entire root system damaged with no regrowth. Ratings were performed 28, 35 and 42 d after permanent flood in 1991 and 1992.

At maturity, before harvest, a representative height (three plants/plot) was measured at random from each plot to assess the difference in growth between the treated and untreated plots. All plots were harvested (21 October 1991 and 4 September 1992) and the grain weight was determined to assess yield loss due to root damage. Percent height (% Ht Diff) and yield (% Yd Diff) differences were calculated as follow: % Ht Diff = ([treated Ht - untreated Ht]/treated Ht) x 100; and % Yd Diff = ([treated Yd - untreated Yd]/treated Yd) x 100.

Data were subjected to analysis of variance (ANOVA) using SAS General Linear Model Procedure (SAS Institute 1985). Means were separated using Tukey's Studentized
Range (HSD) test. A paired T Test (Proc means, percent difference) was used to compare the treated and untreated variables. The root damage rating data were analyzed as a split-split-plot in which date of sampling was the sub-sub-plot.

Results and Discussion

Carbofuran treatment had a significant effect on larval population during both years (1991: df = 1,5; F = 5.67, p < 0.0001; 1992: df = 1,5; F = 216.5, P < 0.0001). Significant differences were found in larval populations among the lines evaluated in 1991 (df = 9,42; F = 3.27, p < 0.0043) and 1992 (df = 8,40; F = 4.49, P < 0.0006) (Table 4.1). There was no line by insecticide interaction for rice water weevil larval population in 1991 but there was a significant (df = 8,45; F = 2.69, P < 0.016) interaction between line and insecticide in 1992. However, in both years, none of the lines evaluated had significantly lower number of rice water weevil larvae than the susceptible check, Mars. This indicates that none of the lines evaluated showed antibiosis or antixenosis. Line 953541 had a lower number of larvae/core than Mars in 1991 and 1992, but differences were not significant. Larval populations in carbofuran treated plots ranged from 4.4 to 11.3 larvae/core in 1991 and from 3.1 to 6.0 larvae/core in 1992 with larvae predominately in the small size category.

Root damage ratings were high overall at 28 d postflood in the untreated plots for all the lines
Table 4.1. Mean number of rice water weevil larvae per core in rice anther culture lines evaluated for tolerance, Crowley, La., 1991-1992

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>1991</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated</td>
<td>Treated</td>
</tr>
<tr>
<td>952836</td>
<td>47.9 ± 3.6a</td>
<td>9.7 ± 1.2a</td>
</tr>
<tr>
<td>953508</td>
<td>31.7 ± 4.4ab</td>
<td>9.1 ± 1.7a</td>
</tr>
<tr>
<td>953509</td>
<td>35.6 ± 3.0ab</td>
<td>9.5 ± 1.4a</td>
</tr>
<tr>
<td>953510</td>
<td>42.3 ± 2.8a</td>
<td>10.1 ± 1.4a</td>
</tr>
<tr>
<td>953511</td>
<td>38.1 ± 2.5ab</td>
<td>11.3 ± 1.2a</td>
</tr>
<tr>
<td>953527</td>
<td>41.5 ± 3.0a</td>
<td>8.5 ± 1.0a</td>
</tr>
<tr>
<td>953541</td>
<td>15.0 ± 5.3b</td>
<td>4.4 ± 1.2a</td>
</tr>
<tr>
<td>LEMONT</td>
<td>42.9 ± 3.3a</td>
<td>9.5 ± 1.2a</td>
</tr>
<tr>
<td>MARS</td>
<td>32.7 ± 3.0ab</td>
<td>10.1 ± 1.0a</td>
</tr>
<tr>
<td>WC1403</td>
<td>40.2 ± 3.2a</td>
<td>9.6 ± 1.6a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
evaluated in 1991 and 1992 (Figs. 4.1 and 4.2). No line by sampling date interaction was found for root ratings in 1991, but there was a significant interaction between line and sampling date in 1992. Lines 952836 and 953527 displayed significant decrease in root damage ratings in 1991, but decrease was not significant in 1992. This suggests that lines 952836 and 953527 have potential for recovering from larval root pruning damage. Root damage ratings were relatively constant within dates and overall low in the treated plots (Figs. 4.3 and 4.4). This indicates that larval root pruning damage was effectively reduced by the carbofuran treatment.

Although all the lines tested were regenerated from one parent cultivar (Lemont), plant height was highly variable. There was no line by insecticide interaction for plant height in 1991, but there was a significant (df = 8,40; $F = 3.62$, $p < 0.0025$) interaction between line and insecticide in 1992. Plants in treated plots were significantly ($p < 0.05$) taller than plants in the untreated plots during both years (Tables 4.2 and 4.3).

In 1991, grain yield differed significantly (df = 9,40; $F = 16.75$, $p < 0.0001$) among the lines evaluated (Table 4.2). In 1992, yield differences among lines were not significant (df = 8,35; $F = 1.7$, $p > 0.13$) plots (Table 4.3). There was a significant line by insecticide interaction for grain yield during both years (1991: df = 9,43; $F = 3.73$, $p < 0.0016$; 1992: df = 8,40; $F = 3.07$, $p <$
Fig. 4.1. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 4.2. Root damage ratings at 28, 35, and 42 d postflood of plants in untreated plots of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Fig. 4.3. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
ROOT DAMAGE RATING

28 d POSTFLOOD  35 d POSTFLOOD  42 d POSTFLOOD

CULTIVAR/LINE

952836 953508 953509 953510 953511 953527 953541 Lemont Mars WC1403
Fig. 4.4. Root damage ratings at 28, 35, and 42 d postflood of plants in treated plots of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992. Bars with the same letters within lines indicates means are not significantly different ($P > 0.05$), Tukey's Studentized Range (HSD) Test (SAS Institute 1985).
Table 4.2. Height and yield of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991

<table>
<thead>
<tr>
<th>Cultivar/ line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha) (mean ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>952836</td>
<td>142.7</td>
<td>125.7</td>
</tr>
<tr>
<td>953508</td>
<td>92.5</td>
<td>83.3</td>
</tr>
<tr>
<td>953509</td>
<td>99.5</td>
<td>88.4</td>
</tr>
<tr>
<td>953510</td>
<td>95.3</td>
<td>83.5</td>
</tr>
<tr>
<td>953511</td>
<td>96.5</td>
<td>86.8</td>
</tr>
<tr>
<td>953527</td>
<td>121.2</td>
<td>108.7</td>
</tr>
<tr>
<td>953541</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LEMONT</td>
<td>95.9</td>
<td>81.1</td>
</tr>
<tr>
<td>MARS</td>
<td>110.0</td>
<td>98.1</td>
</tr>
<tr>
<td>WC1403</td>
<td>115.8</td>
<td>102.4</td>
</tr>
</tbody>
</table>

¹ % Ht diff = ([treated height - untreated height]/treated height)*100.

* Indicates significant at P < 0.05 (Paired T test).

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range (HSD) Test [SAS Institute 1985]).
Table 4.3. Height and yield of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1992

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Height (cm)</th>
<th>Grain yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Untreated</td>
</tr>
<tr>
<td>952836</td>
<td>154.16</td>
<td>143.44</td>
</tr>
<tr>
<td>953508</td>
<td>84.77</td>
<td>79.72</td>
</tr>
<tr>
<td>953509</td>
<td>85.36</td>
<td>79.31</td>
</tr>
<tr>
<td>953510</td>
<td>86.72</td>
<td>80.72</td>
</tr>
<tr>
<td>953511</td>
<td>84.83</td>
<td>79.16</td>
</tr>
<tr>
<td>953527</td>
<td>111.26</td>
<td>106.20</td>
</tr>
<tr>
<td>953541</td>
<td>84.88</td>
<td>75.83</td>
</tr>
<tr>
<td>MARS</td>
<td>104.83</td>
<td>101.83</td>
</tr>
<tr>
<td>WC1403</td>
<td>125.53</td>
<td>119.20</td>
</tr>
</tbody>
</table>

¹ % Ht diff = ([treated height - untreated height]/treated height)*100.

* Indicates significant at $P < 0.05$ (Paired T test).

Means followed by the same letter within column are not significantly different ($P > 0.05$, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
suggesting that the lines evaluated responded differently to carbofuran treatment with regard to grain yield. When yield differences between treated and untreated plots were determined for individual lines only two lines (952836, 953527) did not show significant differences during both years (Figs. 4.5 and 4.6).

The height difference between plants in the treated plots and plants in the untreated plots can be attributed to the high rice water weevil larval population in the untreated plots and the resulting high levels of root pruning. However, in a previous study, carbofuran was found to influence plant growth and thereby may increase height (Venugopal 1981). Therefore carbofuran treatment may have contributed to the significant height differences observed between plants in treated and untreated plots. Nevertheless, when yield data were pooled (Figs. 4.5 and 4.6), lines 952836 and 953527 showed tolerance to rice water weevil larval feeding. These two lines averaged higher yields than their parent (Lemont) in 1991, and the check cultivar, Mars, in 1991 and 1992 (Tables 4.2 and 4.3). In addition, lines 952836 and 953527 had the lowest yield reduction in the untreated plots during both years.

In 1992, poor germination occurred in most of the test lines as a result of seed damage by the angoumois grain moth, *Sitotroga cerealella* Oliver, during storage. Hence, seed damage may have contributed to differential germination among the lines with the exception of Mars
Fig. 4.5. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice anther culture lines evaluated for tolerance to the rice water weevil, Crowley, La., 1991. Bars with * indicates that yield loss is significant. Paired T test results were: 95-2836, $T = 2.7$, $P > 0.05$; 95-3508, $T = 2.1$, $P > 0.09$; 95-3509, $T = 3.7$, $P < 0.02$; 95-3510, $T = 4.1$, $P < 0.009$; 95-3511, $T = 3.8$, $P < 0.01$; 95-3527, $T = 1.9$, $P > 0.1$; Lemont, $T = 8.8$, $P < 0.0009$; Mars, $T = 10.9$, $P < 0.0001$; WC1403, $T = 9.3$, $P < 0.0002$. 
Fig. 4.6. Percent yield loss in untreated plots (difference between treated and untreated as a percent of treated plots) of rice anther culture lines evaluated for resistance to the rice water weevil, Crowley, La., 1992. Bars with * indicates that yield loss is significant. Paired T test results were: 95-2836, T = 1.1, P > 0.3; 95-3508, T = 4.0, P < 0.01; 95-3509, T = 5.7, P < 0.002; 95-3510, T = 3.9, P < 0.01; 95-3511, T = 1.5, P > 0.2; 95-3527, T = 1.9, P > 0.1; 95-3541, T = 3.0, P < 0.03; Mars, T = 5.5, P < 0.002; WC1403, T = 5.0, P < 0.007.
(seed obtained from Louisiana Foundation Seed, Rice Research Station). The seed damage may have subsequently affected the yield and thus, explains why line 952836 did not produce a higher yield than the susceptible check Mars in 1992.

Tolerance in lines 952836 and 953527 may be attributed to their ability to recover from root damage, which enhanced nutrient uptake during the latter vegetative growth period. Our results corroborate the findings by Grigarick (1974) and Grigarick et al. (1976) in California and Gifford and Trahan (1975) in Louisiana who previously suggested that there is a relationship between tolerance and root characteristics. Grigarick (1974) found that line 6112 from I.R.R.I. exhibited tolerance to the rice water weevil as a result of high root weight and increased tillering.

Isely and Schwardt (1934) reported that the degree of rice water weevil infestation depends upon the age of the rice plant. They found that when 21 and 36 d old plants were flooded simultaneously in adjacent plots, rice water weevil larval populations were much higher on roots of 21 d old plants than 36 d old plants. Their results show that adult oviposition decreases as the plant matures. Consequently, rice plants with the ability to recover from root pruning damage will compensate for growth as oviposition is minimized or stops in the late vegetative stage.
Based on results from this study, it appears that regrowth of new roots or regeneration of the damaged roots is an important contributing factor of tolerance in rice to the rice water weevil. It also is clear that resistance can be obtained from anther culture of a susceptible cultivar. Indeed, Croughan and Quisenberry (1989) demonstrated that the level of resistance in bermudagrass to the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), was increased through tissue culture. White and Irvine (1987) found that sugarcane plants regenerated from a cultivar susceptible to the sugarcane borer, *Diatraea saccharalis* (F.), exhibited variable levels of borer resistance.

In this study, line 952836, which showed tolerance to the rice water weevil, is too tall and prone to lodging and thus, would not be considered as a potential commercial cultivar. Line 953527, although not much taller than the check cultivar Mars, has a poor plant type characterized by inconsistency in plant height and extra short grain type. Lines 953508, 953509 and 953510 had similar plant type and stature as the parent cultivar Lemont but did not exhibit resistance to rice water weevil. Because the resistant lines have poor plant type, they may be used in a rice breeding program as sources of resistant germplasm that can be incorporated into commercial cultivars.
References - Chapter IV


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.


resistance to the rice water weevil, pp. 322-323. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening tissue culture lines for resistance to the rice water weevil, pp. 324-325. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990c. Screening rice lines for resistance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990d. Screening rice breeding lines for tolerance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


CHAPTER V

INVESTIGATION OF RICE ANTIXENOSIS AND ANTIBIOSIS TO THE RICE WATER WEEVIL (COLEOPTERA: CURCULIONIDAE)
The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most destructive insect pest of rice, *Oryza sativa* L., in the southern United States (Webb 1914, Newsom and Swanson 1962, Bowling 1967). Adult foliage feeding is usually considered unimportant, but larval feeding on roots is economically significant. Yield losses of more than 1120 kg per ha can occur under severe larval infestation (Newsom and Swanson 1962).

The possibility of cultivar resistance of rice to the rice water weevil was initially considered by Isely and Schwardt (1934) who noted that some cultivars had higher number of larvae than others. Research on rice resistance to the rice water weevil has been complicated by the aquatic habit of both larvae and adult. Low to moderate levels of tolerance have been identified in a few exotic rice genotypes by Gifford and Trahan (1975) and Grigarick et al. (1976). However, identification of sources of rice antibiosis (type of resistance in which physical or chemical characteristics of the plant adversely affect the biology of the insect pest) and antixenosis (type of resistance in which the plant acts as a poor host and the insect pest selects an alternate host plant) to the rice water weevil has been difficult. Some researchers (Robinson et al. 1981, Smith and Robinson 1982, N'Guessan et al. 1990a, 1990b) have identified a number of rice lines with lower larval populations than susceptible cultivars. However, it has been difficult to determine whether the low
larval populations in those lines is due to antibiosis or antixenosis characteristics of the plant. The objective of this study was to determine rice water weevil antibiosis and antixenosis in selected rice lines.

Materials and Methods

Five lines (8721941, 8723463, 8723518, 8725417, 8825454) were selected for this study. These lines were obtained from a preliminary field screening in 1990 of 40 Louisiana breeding lines, based on observed low numbers of rice water weevil larvae on roots.

In 1991, a choice experiment was conducted in the greenhouse. The experimental design was a randomized block design with five replicates. In 1992, a similar experiment was conducted with 10 replicates. A susceptible cultivar (Mars) was used as check during both years. Greenhouse conditions were ambient to temperature and photoperiod in May and June 1991 and 1992. All the lines were seeded (11 May 1991 and 17 May 1992) in separate pots (13 cm diam. by 10 cm deep) filled with Crowley silt loam soil.

Before permanent flood (6 June 1992), plants were thinned to six plants per pot. The pots were placed in a basin made of 2.1 x 1.4 x 0.3 m wooden frame secured with visquinv (plastic) to hold the flood water. A pot of each line was arranged randomly in a circle and placed within a cage. Cages were made of cylindrical metal frames (0.5 m diam by 0.62 m high) covered with a 40 mesh vinyl screen that prevented adult weevils from escaping. On the day of
permanent flood, male and female adult rice water weevils in copula were collected from the field and confined within the cages (18 insects per cage) for a period of 1 wk. The cages and adult weevils on the plants were removed to allow plants to develop.

Twenty-one d post-infestation, the content of each pot was washed through a 40-mesh copper sieve. The residue was placed in a saturated sodium chloride solution and floating rice water weevil larvae and pupae were counted and classified as small (0-3 mm), medium (3-6 mm) and large (large [6-10 mm] + pupa). All data were analyzed by analysis of variance (ANOVA) using the general linear model procedure (GLM) of SAS (SAS Institute 1985). Mean separations were determined using Tukey's Studentized Range (HSD) test.

Results and Discussion

Rice water weevil larval populations differed significantly among the lines evaluated during both years (1991: (df = 5, 20), $F = 11.62, P < 0.0001$; 1992: (df = 6, 54; $F = 8.67; P < 0.0001$) (Table 5.1). Lines 8723518, 8725417 and 8825454 consistently averaged significantly ($P < 0.05$) lower number of larvae than the susceptible check (Mars) during both years, indicating that these lines exhibited some resistance to the rice water weevil.

An assessment of the percentage of larval populations in the different size categories for the three lines that appeared to be resistant revealed that 40 to over 50% of
Table 5.1. Mean number of rice water weevil larvae per pot in selected Louisiana breeding lines evaluated for resistance, Crowley, La., 1991-1992

<table>
<thead>
<tr>
<th>Cultivar/line</th>
<th>Larvae/core (mean ± SE)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8721941</td>
<td>55.0 ± 9.7ab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8723463</td>
<td>60.4 ± 9.7a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8723518</td>
<td>32.6 ± 4.4bc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8725417</td>
<td>30.2 ± 2.7bc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8725454</td>
<td>25.4 ± 3.6c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARS</td>
<td>73.6 ± 9.8a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8721941</td>
<td>43.2 ± 7.5a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8723463</td>
<td>31.6 ± 4.4ab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8723518</td>
<td>17.8 ± 1.3c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8725417</td>
<td>21.2 ± 2.1bc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8725454</td>
<td>24.0 ± 1.8bc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARS</td>
<td>48.8 ± 2.9a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter within column are not significantly different (P > 0.05, Tukey's Studentized Range [HSD] Test [SAS Institute 1985]).
the larvae found in these lines were in the large category (Figs. 5.1 and 5.2). This indicates that plant characteristics did not affect larval development, and consequently the lines did not exhibit antibiosis against rice water weevil larvae.

Smith and Robinson (1982) reported that a growth inhibiting factor may contribute to low larval populations observed in some rice lines. However, the results in this study show that antibiosis was not evident in the lines evaluated. Painter (1951) stated that death of insects on resistant plants frequently takes place during the first instar. Consequently one would expect to see fewer larvae in the medium and large category at 21 d postflood if antibiosis was present in lines 8723518, 8723417 and 8825454.

The low populations of larvae observed on roots of lines 8723518, 8723417 and 8825454 may be due to preference of the susceptible check, and to some extent lines 8721941 and 8723463, for adult oviposition. Indeed it has been reported that even in natural ecosystems, some plants escape attack by insects because adjacent plant species may be more preferred for oviposition or feeding (Ehrlich and Raven 1964, Price 1984). Preference or nonpreference of plant by insects has been attributed to the existence of chemical and/or physical plant characteristics that may attract or repel a particular insect species (Fraenkel 1959, Kogan 1977, Price 1984, Smith 1989).
Fig. 5.1. Percentage of rice water weevil larval populations in different size categories for three Louisiana breeding lines exhibiting resistance, Baton Rouge, La., 1991.
Fig. 5.2. Percentage of rice water weevil larval populations in different size categories for three Louisiana breeding lines exhibiting resistance, Baton Rouge, La., 1992.
PERCENT LARVAL POPULATION

CULTIVAR/LINE

MARS

8723518

8725417

8725454

100

80

60

40

20

0

SMALL

MEDIUM

LARGE
It has also been reported that larval populations found on the roots are strongly correlated to adult foliage feeding (Rourk 1975). Thus, preference or nonpreference of rice lines for oviposition by the rice water weevil could be due to differential concentrations of a chemical compound, probably an arrestant or a feeding stimulant, in these lines. However, because egg data were not taken, the possibility of ovicidal antibiosis cannot be excluded. Therefore, further studies on the ecological relationship between the adult rice water weevil and rice volatiles may be needed to elucidate the cause of rice water weevil antixenosis in rice.


N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening rice breeding lines for tolerance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


resistance, pp. 260-270. In 73rd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.


The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is an important insect pest of rice, *Oryza sativa* L., in the rice growing regions of the United States and recently Japan and Korea. Although insecticide application has been effective in controlling this insect pest, other control tactics are needed for an integrated pest management approach. The utilization of insect resistant cultivars is an alternative to chemical control as well as an adjunct to other control methods. Indeed, insect resistance has played a very important role in the management of several other insect pests of rice such as planthoppers, leafhoppers and stem borers in many countries, including Bangladesh, China, Colombia, Cuba, India, Indonesia, Korea, Philippines, Solomon Islands, Sri Lanka, Thailand and Vietnam.

The studies reported herein have added important information to rice water weevil resistance in rice. Two lines regenerated from anther culture (95-2836 and 95-3527), two Louisiana breeding lines (8720906 and 8721937), two lines regenerated from tissue culture (112 and 4754), and five lines of various sources (AL6029, LA2218, TX22041, URN199, URN200) exhibited at least moderate tolerance to the rice water weevil. These lines did not have significant ($P < 0.05$) yield differences between treated and untreated plots in spite of supporting high larval populations in the untreated plots. Tolerance was
expressed as the ability of the lines to regrow new roots or regenerate the damaged roots. Such recovery from root pruning damage compensate for growth and increase grain yield.

Antixenosis and antibiosis tests revealed that two tissue culture lines (244, 2232), three Louisiana breeding lines (8723417, 8723518, 8825454) and two Texas lines (TX12685 and TX13079) had a moderate level of resistance to the rice water weevil. These lines sustained significantly (P < 0.05) lower larval populations than the susceptible check Mars. Assessment of the percentage of larval populations in different size categories (small [0-3 mm], medium [3-6 mm] and large [6-10 mm]) suggested that antibiosis against the larvae was not the mechanism of resistance in the lines evaluated. The low larval populations in the lines exhibiting resistance may be attributed to nonpreference for adult oviposition. However, because egg data were not recorded in this study, the low larval populations could be due to ovicidal antibiosis.

Based on the data, it appears that the primary mechanisms of rice water weevil resistance in rice are tolerance, expressed as regrowth of new roots and regeneration of the damaged roots, and antixenosis, attributed to nonpreference for oviposition by the adult weevil. Larval antibiosis was not an evident mechanism of rice water weevil resistance in the rice lines evaluated. However, antibiosis was difficult to evaluate because the
aquatic habit of the larvae prevents adequate monitoring of larval development from egg to adult stage. Therefore, further studies are needed to elucidate the mechanism of resistance in the lines displaying low larval populations. It is also evident that both anther culture and tissue culture are techniques that can be used to produce rice lines resistant to the rice water weevil from a susceptible parent.


Bowling, C. C. 1967b. Test with insecticides as seed treatments to control rice water weevil. J. Econ. Entomol. 60: 18-19.


Nilaparvata lugens (Stal) populations as influenced by method and timing of insecticide applications in lowland rice. Environ. Entomol. 11: 78-84.


Ingram, J. W. 1927. Insects injurious to the rice crop. USDA Farmers Bulletin 1543.


Isley, D. and H. H. Schwardt. 1934. The rice water weevil. Arkansas Agricultural Experiment Station Bulletin 299.


Kennedy, B. M. 1980. Nutritional quality of rice endosperm. pp 439-469 In Bor S. Luh, Ed., Rice: production and


Latson, L. N. and G. B. Trahan. 1977. Host plant resistance to the rice water weevil, pp 113-139. In 69th Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.


N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990b. Screening tissue culture lines for resistance to the rice water weevil, pp. 324-325. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990c. Screening rice lines for resistance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

N'Guessan K. F., S. S. Quisenberry, G. B. Trahan, and P. A. Bollich. 1990d. Screening rice breeding lines for tolerance to the rice water weevil, pp. 326-327. In 82nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Newsom, L. D. and M. C. Swanson. 1962. Treat seed to stop rice water weevil damage. La. Agric. 5: 4-5.


Quisenberry, S. S., G. B. Trahan, A. M. Heagler, B.
management as a control strategy for rice water weevil
(Coleoptera: Curculionidae). J Econ. Entomol.
85(3): 1007-1014.

Rao, Y. S. and J. P. Kulshreshtha. 1985. Insect pests of
rice, pp. 550-590. In Rice research in India. Indian
Council of Agricultural Research, New Delhi.

Effects of insecticides on Nilaparvata lugens and its
predators: spiders, Microvelia atrolineata and

water weevil host plant resistance studies, pp. 155-
167. In 70th Annual Progress Report, Rice Experiment
Station, Louisiana Agricultural Experiment Station.

water weevil host plant resistance evaluations, pp.
113-122. In 71st Annual Progress Report, Rice
Experiment Station, Louisiana Agricultural Experiment
Station.

water weevil: water management as a cultural control
method, pp. 204-211. In 72nd Annual Progress Report, Rice
Experiment Station, Louisiana Agricultural Experiment
Station.

water weevil host plant resistance: preliminary and
advanced insect resistance nurseries, pp. 193-196. In
72nd Annual Progress Report, Rice Experiment Station, Louisiana Agricultural Experiment Station.

Evaluation of rice lines for rice water weevil
resistance, pp. 260-270. In 73rd Annual Progress
Report, Rice Experiment Station, Louisiana
Agricultural Experiment Station.

water weevil plant resistance: initial evaluation of
rice P.I. lines, pp. 253-255. In 74th Annual Progress
Report, Rice Experiment Station, Louisiana
Agricultural Experiment Station.

Robinson, J. F, C. M. Smith, G. B. Trahan, and S.
Stillings. 1983. Rice water weevil control: evaluation
of seed treatments, pp. 225-227. In 75th Annual


Tucker, E. S. 1912. The rice water weevil and methods for its control. USDA Bureau Entomol. Circular 152.


VITA

François Kouame N'Guessan was born in Pakouabo/Bouaflé, Côte d'Ivoire, on 1 May 1962. He graduated from "Lycée Moderne de Bouaflé" in 1981. He received his B.S. in 1985 from the University of Abidjan, Côte d'Ivoire. In March 1986, Mr. N'Guessan was granted a scholarship by the Ministry of Scientific Research of the Côte d'Ivoire Government to continue graduate level studies in the United States. In 1989, Mr. N'Guessan received his M.S. in Entomology from the University of Georgia, Athens, Georgia, under the direction of Dr. Richard B. Chalfant. In 1990, Mr. N'Guessan joined the Department of Entomology, Louisiana State University, where he was granted a research assistanship and has since been working under the direction of Dr. Sharron S. Quisenberry.
Candidate: Francois K. N'Guessan
Major Field: Entomology
Title of Dissertation: Factors Contributing to Resistance in Rice to the Rice Water Weevil, Lissorhoptrus Oryzophilus Kuschel

Approved:

[Signatures]

Major Professor and Chairman
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:
March 17, 1993