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Development of integrated pest management for sugarcane borer, Diatraea saccharalis in rice

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DEVELOPMENT OF INTEGRATED PEST MANAGEMENT FOR SUGARCANE BORER, *DIATRAEA SACCHARALIS* IN RICE

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ABSTRACT

Rice is grown over an area of approximately 500,000 acres in Louisiana. The lepidopteran stem borer complex attacking rice in the southern U.S includes stalk borer *Chilo plejadellus* Zincken, sugarcane borer (SCB) *Diatraea saccharalis* (F.) and Mexican rice borer, *Eoreuma loftini* Dyar. With the increasing impact of stem borers in Louisiana, an urgent need exists to develop strategies for management. Currently, no IPM program is in place for stem borers in Louisiana rice and research has been initiated to develop an IPM program for these pests.

The first objective of this research was focused on host plant resistance. For this objective, oviposition preference and larval performance of sugarcane borer on commonly grown rice cultivars in Louisiana were investigated. Results from the oviposition preference study revealed significant differences among cultivars. Overall females of *D. saccharalis* preferred ovipositing on the upper sides of the leaves of rice plants. In the performance study, three different measures of performance were used. Results from these studies revealed significant differences among varieties for these measures of performance. Results also revealed a strong correlation between different measures of performance as well as between performance and preference. Results from the compensation study revealed differences in compensatory response of same eight cultivars. In the silicon soil amendment study, a significant increase in silicon content of rice plants supplemented with calcium silicate was observed compared to the control plants. Soil Si amendment led to lower relative growth rates and reduced boring success of sugarcane borer larvae on. Studies were conducted to evaluate the efficacy of Dermacor seed treatment against sugarcane borer. Dermacor

seed treatment was the most effective among different insecticides used in a field study and significantly increased larval mortality in lab and greenhouse experiments.

These studies will help facilitate scouting for sugarcane borer in the field and improvement in insecticide timing. Potential exists for current use of these (moderately resistant) cultivars in IPM programs and as sources of resistance in breeding programs for stem borer resistance. Soil Si amendment and Dermacor seed treatments has the potential to fit into the IPM program.

CHAPTER 1: INTRODUCTION

Rice

Worldwide, rice is planted on 159 million hectares with about 1.18 million hectares in the United States (USDA FAS 2012). Rice is a staple for more than half of the world's population and is second to wheat in its importance, providing at least half of the daily calories consumed by humans globally (IRRI 2011). Rice is cultivated in more than 50 countries across Africa, Asia, Australia, Europe, North and South America (USDA 2012) and rice farms cover approximately 11% of the world's arable land (IRRI 2011). Therefore, the development and application of research technologies in rice have the potential to significantly impact the world population and will also have substantial effect on the environment.

The worldwide annual production of rice rose from 350 million tons in the 1980's to over 600 million tons in 2007 (IRRI 2007). The leading producers of rice are (in decreasing order) China, India, Indonesia, Bangladesh, Vietnam, Thailand, Burma, Japan, Philippines, Brazil, and the United States. The annual production in the U.S. is 8 million metric tons, contributing about 2% of world rice production, and 80% of the total production in North and Central America (USDA FAS 2012). Although rice production in U.S is low, it is one of the largest exporters of rice after Thailand and Vietnam, with more than 10 % of global rice exports (USDA ERS 2012). In 2011, the value of US rice harvest was approximately $ 2.63 billion, and in Louisiana, the rice production was worth over $ 360 million (USDA FAS 2012).

The date of rice introduction into the United States is uncertain, however the report of first rice cultivation was conducted by Dr. Henry Woodward of Charleston, S.C., in 1685 (Dethloff 1988). Dr. Woodward obtained rice seeds from Captain John Thurber, who had docked his storm

damaged ship to Charleston from the island of Madagascar. The production of rice spread rapidly in this area and by 1700, South Carolina was exporting 181437 pounds of rice annually (LSU Agcenter 2006). Rice production began in Louisiana as early as 1718, introduced by a group of French settlers, led by Jean-Baptiste Le Moyne de Bienville (Anonyomous 1913). The Mississippi delta has proven to be an ideal location for rice and most rice in the United States is grown in this area. The rice producing states in the U.S. are Arkansas, California, Florida, Louisiana, Mississippi, Missouri, and Texas. Rice is cultivated on 145372 hectares in Louisiana (LSU Agcenter 2012) with an average yield of 7175 kg per hectare (USDA NASS 2012).

Insect pests of rice

A major limiting factor worldwide for rice production is damage by insect pests (Pathak and Khan 1994). In the southeastern United States, the main pests are the rice water weevil, *Lissorhoptrus oryzophilus* (Coleoptera: Curculionidae) (Smith 1983, Way 1990), the rice stink bug, *Oebalus pugnax* (Hemiptera: Pentatomidae) and a group of Lepidopterous stem borers; the rice stalk borer, *Chilo plejadellus*, the European corn borer, *Ostrinia nubialis* and the sugarcane borer, *Diatraea saccharalis* (B.A. Castro, LSU AgCenter, Department of Entomology, personal communication). Moreover, a third stem-boring species, the Mexican rice borer, *Eoreuma loftini* Dyar, has moved into Louisiana through the Texas rice belt predicted by Reay-Jones et al (2008) and has the potential for significant economic damage (Reay-Jones et al., 2008). It was first found in 2008 from two pheromone traps in Louisiana, approximately 8 km from rice fields near the Texas border (Hummel et al. 2010). Reay-Jones et al (2008) predicted that this pest will infest the entire Louisiana rice and sugarcane industry by 2035 and may cause annual losses of up to $220 million.

Stem borers have historically been considered as important pest of rice in Louisiana (Douglous and Ingram 1942, Oliver et al 1972). Their incidence decreased in the 1980's pertaining to the use of resistant cultivars, improved cultural practices and extensive use of insecticides for stink bugs (Way 1990). Therefore, use of insecticides was not justified during this period. But in the recent years, farmers have experienced an increase in number of infestations due to stem borers (Castro 2004). In 2002, for example, approximately 1214 hectares of rice in Concordia Parish were infested with *D. saccharalis* which damaged 70 to 95 % of the rice crop on some farms (Castro et al. 2004). *Diatraea saccharali* is responsible for causing upto 90% of the total insect damage to sugarcane in Louisiana (Reagan et al. 1972, Schexnayder et al. 2001). *Diatraea saccharalis* can also be a serious pest of rice in Louisiana and Texas (Way 2003, Castro et al. 2004), where this crop was grown on 166, 880 and 72,843 hectares, respectively, in 2011 (LSU AgCenter 2012, Texas A&M AgriLife 2012).

Chemical control is the most widely used management tactic but it is not very cost-effective. Insecticides are expensive and their use can have adverse environmental effects on non-target organisms, both terrestrial and aquatic (Chelliah & Bharathi, 1994, Litsinger et al. 2005). There are no economic thresholds for stem borers in rice, so it becomes hard to predict when to treat leading to indiscriminate use of insecticides. The feeding habit of stem borers shelters them from non-systemic insecticides and reduces effectiveness of insecticides. Likewise biological control has not been found feasible to control stem borers in rice in temperate climates such as the United States (Lv et al 2011). Host plant resistance may be an appropriate and important tactic against stem borers (Chaudhary et al 1984). Because rice genotypes exhibit various resistance levels, cultivar resistance is anticipated to play an increasing role in stem borer IPM (Way et al. 2006, Reay-Jones et al. 2007b).

With the introduction of *E. loftini,* the use of susceptible cultivars, inadequate cultural practices, the stem borer pressure has been increasing along the Gulf Coast sugarcane and rice industries (Castro et al. 2004, Reay-Jones et al. 2005). Regardless of their importance, currently there is no sound management program for stem borers in rice. With the increasing impact of stem borers on rice there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics. Therefore, this research project is focused on development of integrated pest management program for *D. saccharalis* in Louisiana rice.

Studies conducted

A study was first conducted to quantify the oviposition preference of *D. saccharalis* on different rice cultivars. In this oviposition behavior study, greenhouse experiments using cultivars widely grown in Louisiana demonstrated consistent differences in the preference of *D. saccharalis* for oviposition on these cultivars. In addition, *D. saccharalis* females oviposited significantly more egg masses on the adaxial (dorsal) than on the abaxial (ventral) surfaces of leaves in greenhouse experiments, regardless of the plant age and cultivar. Following this, another study was conducted to characterize variation in resistance among those eight different rice cultivars based on larval performance and oviposition preference of *D. saccharalis* (Chapter 3). This was the first study on larval performance of *D. saccharalis* on different rice cultivars in Louisiana where three different measures of larval performance; boring success, relative growth rate of larvae and time till entry into the stems were investigated. This study also investigated relationship between larval performance and oviposition preference. In addition, compensation mechanisms against D. *saccharalis* infestation in these cultivars were also examined (Chapter 4)

In order to make progress in cultural practices for management of *D. saccharalis,* a study was conducted to investigate the potential of Silicon (Si) soil amendments to increase rice resistance to *D. saccharalis* (Chapter 5). In this study effect of Si on the relative growth rates and boring success of *D. saccharalis* larvae in a susceptible and moderately resistant rice cultivar was investigated. Lastly, to have a balanced approach towards development of IPM for *D. saccharalis*, a study determined the efficacy of different rates of Dermacor-X-100®seed treatment on *D. saccharalis* (Chapter 6). The ultimate goal of this research was to develop a more comprehensive stem borer management program that included all novel tactics to manage the stem borer populations on an areawide basis with least disruption of the environment.

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CHAPTER 2: LITERATURE REVIEW

Distribution and host plants

The stem borer, sugarcane borer, *Diatraea saccharalis* (F.), belongs to the family Crambidae. *Diatraea saccharalis* was introduced into Louisiana during the 19th century from West Indies and South America in the 1850s and subsequently spread to the adjacent southern states (Stubbs & Morgan 1902, Holloway et al. 1928 Bowling 1967, Williams et al.1969). Sugarcane borer also occurs throughout the Caribbean, Central America, and the warmer portions of South America (Argentina, Brazil, Ecuador, Peru) (Bleszynski 1969, Pemberton & Williams 1969, Capinera 2009).

It is a major agronomic pest in the southeastern United States. Holloway et al. (1928) reported more than 20 host plants for *D.saccharalis.* In addition to sugarcane (*Saccharum officinarum* L.), it is an economically important pest of corn (*Zea mays* L.), rice (*Oryzae sativa*) and sweet sorghum (*Sorghum bicolor* L. Moench) (Roe et al. 1981). This species also feeds on several non-crop grasses including *Andropogan* spp., *Digitaria* spp., *Eleusine* spp., *Echinochloa* spp., *Hymenachne* spp., *Leptochloa* spp., *Paspalum* spp., *Panicum* spp., and *Sorghum* spp. (Holloway et al. 1928, Bessin & Reagan 1990).

Morphology and life cycle

A detailed description of *D. saccharalis* life cycle, habits, and morphology was provided by Holloway et al. (1928) and a bibliography was authored by Roe (1981). Below is the summarized description of the life cycle as described by Holloway et al (1928):

The eggs are cream-colored, flattened and oval in shape, measuring about 1.16 mm in length and 0.75 mm in width. They are deposited in clusters of about 2-100 eggs and overlap like the scales on a fish. The eggs are white initially, but turn orange with age and then acquire a blackish hue just before hatching. Duration of the egg stage is four to six days. When borers are reared on corn and sugarcane, mean fecundity is about 700 eggs, but only about 425 reared on Johnsongrass (Bessin & Reagan 1990). Female sugarcane borers reared on rice can lay as many as 239 eggs in her lifetime (Castillo & Villarreal 1989). The duration of the egg stage decreases from 16.5 to 4.6 d with increase in temperatures from 15°C to 32°C under laboratory conditions on an artificial diet (King et al. 1975).

Eggs within a cluster hatch about the same time and upon hatching larvae move toward the space between leaf sheaths and plant stems. Larvae mine inside the leaf sheaths and after the second or third molt bore into the stems. The larvae display both summer and winter forms. The larvae are whitish with a brown head and the summer forms bear large brown spots on each body segment whereas the winter forms lack spots. A stout hair originates in each of the spots, or in the case of the winter form, from the location where the spot might appear. Normally there are five to six instars though three to 10 instars are also reported (Capinera 2001).When the larvae are reared on artificial diets, they tend to display six instars. Larvae measure about 2-4 to 20-30 mm in length during one through five instars, respectively (Holloway et al.1928). Roe et al. (1982) reported mean head capsule widths of about 0.29 to 1.32 mm for instar one through five. Larval development time is usually 25 to 30 days during warm weather and 30 to 35 days during cool weather except during the winter when development is arrested.

Diatraea saccharalis overwinters as larvae in stalks of graminaceous plants, pupate in early March, and emerge as adults in late March, early April (Fuchs et al.1979). Peak incidence of diapause (63-71% of the field population) under Louisiana conditions occurs between October and December (Katiyar & Long 1961). Overwintering borer populations can be reduced by destruction of overwintering hosts (Rodriguez-Del-Bosque et al. 1995).

Prior to pupation, the larva within the stem cleans and expands the tunnel leaving only a thin layer of plant tissue for the moth to escape after eclosion. The pupa is elongate and slender about 16-20 mm in length with prominent pointed tubercles on the distal segments. It is yellowish brown to dark brown in color. The pupal duration is about 7 to 8 d under warm conditions between 26 and 33°C, and approximately 13 d at 22°C (King et al. 1975).

The adult is a yellowish brown nocturnal moth with a wing span that measures 18 to 28 mm in males and 27 to 39 mm in females. Adult females start laying eggs at dusk and continue throughout the evening. Oviposition lasts for up to 4 days and the duration of adult stage is 3 to 8 days.

There is potential for four to five generations to occur annually in Louisiana, but moths are abundant only in spring and autumn (Hensley 1971, Fuchs & Harding 1978). In Louisiana and Texas, adults become active by April or May and oviposition can begin on rice as early as May, but economically damaging infestations generally do not occur until August or September (Bowling 1975, Ring et al. 1998). In rice fields, two to three generations can occur annually (Bowling 1975, Ring et al. 1998). The *D. saccharalis* adults breed on other host plants until the rice plants are large enough to feed upon (Bowling 1975).

Damage

The damaging stages of stem borers, the larvae, are internal feeders (Chaudhary et al. 1984). After hatching, the young larvae move between the leaf sheath and stem where they feed inside the leaf sheath. Initial feeding by the larvae in the leaf sheath causes broad longitudinal reddish brown lesions at the feeding sites (Pathak 1968). Young larvae feed inside the leaf sheaths seven to ten days, before they bore into the stem and feed internally. Feeding on plant tissue in the stalks can lead to lodging, deadhearts, whiteheads, and partial whiteheads (Holloway 1928, Castro et al. 2004). At the vegetative stage of rice plant growth, feeding by stem borer larvae results in “deadhearts”, in which the young tillers and the leaves of the tillers die. Partial whiteheads result from larvae feeding on individual kernels late in panicle development. Whiteheads are caused by feeding on the neck of the panicle, which disrupts translocation of nutrients for proper development. Feeding on the panicle shortly after panicle differentiation leads to no panicle emerging from the stalk. Extensive feeding on rice stems can cause plants to lodge because rice plants are not able to support their own weight or cause deadhearts (i.e., when plants do not produce panicles). Sugarcane borer can be more devastating to rice and damage can be worse in rice fields in close proximity to corn or sugarcane (*Saccharum officinarum* L.) (Pathak 1968, Holloway 1928). If injury occurs at an early plant growth stage, borer-injured rice plants can recover partially by production of new tillers (Bondong & Litsinger, 2005, Lv et al. 2008).

Control tactics

1. Host plant resistance

Host plant resistance has been the focus of stem borer management studies in Asia. Thousands of different rice cultivars from the world collection at the IRRI have been screened for

stem borer resistance. Pathak et al. (1971) screened several thousand rice lines and reported some of the lines to be highly resistant. They also reported that susceptibility of most rice cultivars appeared to be positively correlated with oviposition preference of moths. Many morphological, anatomical, physiological and biochemical factors have been reported to be associated with resistance (Chaudhary et al. 1988). Cultivar resistance to stem borers varied from moderate to low levels in these studies. None of the cultivars are completely resistant against stem borers, but differences in levels of resistance are observed among cultivars and these are used as a source of resistance in stem borers control programs (Chandler 1967). There have been quite a few studies on *D. saccharalis* resistance in Louisiana rice cultivars. Oliver et al. (1972) conducted studies on selected lines from the world rice collection and reported fewer larvae and less infestation in some rice lines when compared to a commercial cultivar "Saturn" in small plot trials. Oliver & Gifford (1975) observed that larval growth and development of two stem borer species varied on different rice cultivars but larval response to different rice cultivars was similar for both species. Douglas & Ingram (1942) observed that *D. saccharalis* and *C. plejadellus* were more abundant in rice plants with larger culms.

A recent research in Texas (Way et al. 2006) has focused on varietal differences in injury and yield losses under field conditions. The data from Texas indicate that cultivar Priscilla is highly susceptible to both sugarcane borer and Mexican rice borer damage, while hybrid cultivars were less injured and yielded more than nonhybrid cultivars (Way et al. 2006). Greenhouse studies from Texas have also examined the oviposition preference of *E. loftini* for different rice cultivars. Reay-Jones et al. (2007) reported that the hybrid cultivar XL8 was more attractive than Cocodrie for *E. loftini* oviposition. This latter study suggested that differences exist in the cultivar preferences of different stem boring species in rice. Although oviposition preference was not

known for *D. saccharalis*, Way et al. (2006) suggested that cultivars such as XL8 could act as sinks for *E. loftini* populations and decrease stem borer areawide infestations.

2. Chemical control

Insecticide applications were not justified during the 1980's due to a decrease in stem borer infestations pertaining to the use of resistant cultivars, improved cultural practices and extensive use of insecticides for stink bugs (Way 1990). But in the recent years, farmers have experienced an increase in number of infestations due to stem borers in Louisiana (Castro 2004). Farmers of the Texas rice belt have resumed insecticide sprays to avoid possible economic losses due to stem borers (Beuzelin, 2011). Chemical control has always been a major control tactic in managing stem borer infestations and yield losses in Texas (Browning et al 1989, Reay Jones et al 2007a). In Texas, sugarcane borers caused yield losses upto 60 % in untreated fields (Way et al 2006). Over the past few years stem borer control has been accomplished using pyrethroids applied as foliar sprays (Reay Jones et al 2007a). Two pyrethroid insecticides (lambda-cyhalothrin and zeta-cypermethrin) are currently labeled for stem borer control in U.S rice (Reay-Jones et al. 2007a). Insect growth regulators tebufenozide and novaluron reduce *D. saccharalis* and *E. loftini* injury in sugarcane (Reay-Jones et al. 2005a; Beuzelin et al. 2010) but are less efficient than pyrethroids in rice (Castro et al. 2005; Reay-Jones et al. 2007a). Castro et al. (2005) reported that tebufenozide and methoxyfenozide significantly reduced whiteheads on rice due to *D. saccharalis* in Louisiana but whiteheads in these two treatments were2.3-fold greater on average than plots with the pyrethroids. Reay-Jones et al. (2007) concluded that pyrethroids applied twice during the rice reproductive phase caused the greatest decrease in whiteheads and yield losses, and would increase farmer benefits. However, the effects of insecticide applications on yield losses were highly variable. Although studies have helped to

better time insecticide applications, economic thresholds for stem borers in rice are lacking (Reay-Jones et al. 2007).

3. Cultural control

Overwintering borer populations may be reduced by heavy pasturing of stubble, fall plowing or flooding fields during the winter (Douglas and Ingram 1942). Ratoon rice is very susceptible to stalk borer damage (Way & Espino 2012). However, the impact of such practices has not been quantified. In rice agroecosystem, stem borers breed on alternate hosts (weeds) until the rice plants are large enough to sustain larval feeding (Bowling 1975). Weed management in rice field is typically very good (Kendig et al. 2003) but unmanaged weed hosts surrounding the fields may be an important sources for harboring stem borer population.

4. Biological control

Biological control has not been found feasible to control stem borers in rice in temperate climates such as the U.S (Lv et al. 2011). However, an egg parasite, *Trichogramma* species is reported to provide low levels of *D. saccharalis* control in rice in parts of Texas (Way & Espino 2010).

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CHAPTER 3: PERFORMANCE AND PREFERENCE OF SUGARCANE BORER, *DIATRAEA SACCHARALIS*, ON DIFFERENT RICE CULTIVARS

Introduction

The suitability of a host plant for a given herbivore can vary within a species as well as between species (Compos et al 2011, Denno et al 1995, Hill et al 2002, Johnson et al 2009, Wink 2003). Differences in host plant suitability can be manifested in a number of ways and by a variety of measures such as larval growth rate, pupal weight, fecundity and survival (Awimack and Leather 2002, Osier and Lindroth 2006, Roslin and Saimnen 2009, Ruhola et al 2001, Yamazaki and Ohsaki 2006). The plant traits responsible for differences in host plant suitability include chemical, morphological and phenological traits. Female insects often exhibit a preference for oviposition among different hosts but the concordance of oviposition preference and host suitability (offspring performance) is a controversial issue (Courtney and Kibota 1989, Mayhew 1997, Nylin and Janz 1996, Nyman et al 2011, Price 1994, Thompson 1988, Wiklund 1981).

The sugarcane borer, *Diatraea saccharalis* (F.), is a major agronomic pest in the southern United States. Holloway et al. (1928) reported more than twenty host plants for sugarcane borer. In addition to sugarcane (*Saccharum spp.*), it is an economically important pest of corn (*Zea mays* L.), rice (*Oryza sativa* L.), and sweet sorghum (*Sorghum bicolor* L. Moench) (Roe *et al* 1981). In recent years, rice farmers in the southern United States have experienced increased problems with *D. saccharalis*. In 2002, for example, approximately 1214 hectares of rice in Concordia Parish were infested with *D. saccharalis,* which damaged 70 to 95% of the rice crop on some farms (Castro et al. 2004). In addition to *D. saccharalis*, another stem borer, *Chilo plejadellus* Zincken, is also an occasional pest in rice. Moreover, a third stem-boring species, the Mexican rice borer,

Eoreuma loftini (Dyar), has reached Louisiana (Hummel et al., 2010) and has the potential to cause significant economic losses (Reay-Jones et al., 2008).

With the increasing impact of stem borers on rice in the United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics, including host plant resistance. Chemical control remains the most widely used management tactic but it is not very cost-effective. Insecticides are expensive and their use can have adverse environmental effects on non-target organisms, both terrestrial and aquatic (Chelliah &Bharathi, 1994, Litsinger et al. 2005). The feeding habit of stem borers shelters them from non-systemic insecticides and reduces effectiveness of insecticides. Likewise, biological control has not been found feasible to control stem borers in rice in temperate climates such as the United States (Lv et al 2011). Thus, host plant resistance may be a particularly appropriate and important tactic against stem borers (Chaudhary et al 1984).

In a previous study (Hamm et al.2011), oviposition preference of sugarcane borers was found to differ on eight cultivars of rice widely grown in Louisiana (Hamm et al 2011). The objective of the present study was to characterize variation in resistance among those cultivars and to investigate the relationship between larval performance and oviposition preference. Three different measures of larval performance - boring success, relative growth rate of larvae and time until entry into the stems were used. A previous study (Oliver and Gifford 1972) demonstrated variation in sugarcane borer performance on commercial rice cultivars but this prior study used cultivars that are now obsolete. Characterizing variation in resistance among different cultivars could lead to the use of these cultivars as a source of resistant germplasm in breeding programs and directly to the use of stem borer resistant cultivars in current management programs.

Materials and Methods

Field Study

A field study was conducted in 2009 at the Louisiana State University Agricultural Center Macon Ridge Research Station, Winnsboro, LA, to evaluate the damage caused by *D. saccharalis* (F.) on different rice cultivars. Eight rice cultivars (Table 3.1) that are widely grown in Louisiana (LSU Agcenter 2009) were used. The susceptible check Priscilla and the medium grain cultivar Bengal did not emerge, leaving six cultivars for the experiment. The experiment was laid out in a split plot design with four replications. In each replication, there were two plots for each cultivar, one untreated and one treated with an insecticide. Plots were 1.5 m x 4.5 m in size. Rice seeds were drill planted on 24th June 2009 using recommended seed rates (LSU Agcenter 2009). Standard agronomic practices for drill seeded rice were followed (LSU Agcenter 2009). On August 28th, a foliar insecticide treatment using Karate Z (Lambda-cyhalothrin) @ 183 ml/hectare was applied to the plots designated for treatment. Insecticide was applied using a CO_2 backpack sprayer with a pressure of 310 kpa at 5 km/h. Before harvest, four plants were randomly sampled from each plot to assess *D. saccharalis* damage to rice. Each plant was inspected and the number of stem borer entry or exit holes was counted. Data are presented as average number of holes per plant.

Data analysis: Treatment effects on average number of holes per plant were analyzed as a split plot design using two way analysis of variance in PROC MIXED (SAS institute 1999) with cultivar, treatment and cultivar*treatment as fixed effects and replication and cultivar *replication as random effects. Means were separated using Tukey's HSD test (Tukey 1953). Kenward-Roger adjustments for degrees of freedom in mixed models were applied in the analysis (Littell et al.2002).

Table 3.1: Rice cultivars used in field, greenhouse and lab studies during 2009, 2010, 2011 and 2012

Cultivar	**Rice Type**	**Field study**	**Boring Success**			**RGR**		**Time until Entry**	**Correlation study**
		2009	GH		Lab	GH	Lab	GH	GH
			2009	2010-11					
Cocodrie	Long grain	X	X	X	X	X	X	X	X
Cheniere	Long grain	X	X	X	X	X	X		X
Priscilla	Susceptible check	X[1]	X	X	X	X	X		X
Bengal	Medium grain	X[1]	X	X	X	X	X		X
Jupiter	Medium grain	X	X						
Wells	Long grain	X							
Jazzman	Aromatic long grain			X	X	X	X		X
CL151	Long grain Clearfield			X	X	X	X		X
CL161	Long grain Clearfield	X	X	X	X	X	X		X
XL723	Long grain Hybrid	X	X	X	X	X	X	X	X
XP744	Long grain Hybrid		X						

[1] Rice of this cultivar did not emerge

Greenhouse and laboratory studies

Insects: *Diatraea saccharalis* larvae used in experiments were obtained from a colony maintained continuously in the laboratory at Louisiana State University following the methods of Martinez et al (1988). The colony originated from larvae collected in rice fields near Crowley, LA, in 2005. Larvae were reared in 29.5 ml Solo soufflé cups (AceMart Restaurant Supply, San Antonio, TX) on sugarcane borer artificial diet (Southland Products, Lake Village, AR). Pupae were sexed according to Butt and Cantu (1962) and equal numbers of males and females were placed into three liter plastic buckets with wax paper as a substrate for oviposition. Adults were provided with a 1:1 mixture of honey and beer (Milwaukee's Best Light, Miller Brewing Co., Milwaukee, WI) and distilled water. Eggs were put into eight cell trays for hatching. When the eggs hatched, neonates were placed on artificial diet and reared until use. The colony was maintained under controlled environmental conditions (14L;10D, 28°C ± 2°C, 38% R.H. ± 2% R.H.). Insects collected from rice fields were added annually to the colony to maintain genetic variability.

Plants: Plants for all experiments were grown in a greenhouse located on the campus of Louisiana State University, Baton Rouge. Eight rice cultivars (Table 3.1) were used that collectively represented approximately 75% of the rice acreage in Louisiana from 2009-2012 (LSU Agcenter 2009, 2010, 2011, 2012). The cultivar Priscilla, which is not widely grown in Louisiana, was included in experiments as a susceptible standard (Way et al. 2006). Seeds were planted in a sterilized soil mix (2:1:1, soil: peat moss: sand) in 15cm diameter pots (3.8L) (Hummert International, Earth City, MO) and plants were maintained in the greenhouse conditions under ambient lighting at approximately 29°C-33°C. At the time of planting, approximately 1.2g of 19:5:8 controlled release fertilizer (Osmocote, Scotts Miracle-Gro, Marysville, OH) was added to the soil. Plants were thinned to a density of one plant per pot five to seven days after planting. The

designation of rice plant stages followed the system outlined by Counce et al (2000). All experiments were conducted when plants were at the late tillering stage (50-55 days after planting).

Larval Boring Success

Greenhouse studies: No-choice greenhouse studies using intact plants were conducted in 2009, 2010 and 2011 to investigate the boring success of larvae on widely grown rice cultivars (Table 1). Boring success was defined as the proportion of second instar larvae entering the stems within 24 and 48 h of being placed on plants. Experiments were conducted as randomized block design (RBD) experiments with five replications. Blocks consisted of groups of eight plants, one plant of each cultivar, spatially arranged on a greenhouse bench. At the late tillering stage, plants were infested using ten second instar larvae. Small plastic tube cages (Icon Plastics, Costa Mesa, CA) were used to confine insects on the plants. These tubes were 15 cm long and 2.5 cm in diameter. Tubes were placed over the primary tiller of each plant and foam plugs (WVR International, Suwanee, GA) were used to seal the top and bottom of the tube cages enclosing the stem. Observations of numbers of larvae that remained outside the stems of the plants were taken 24 and 48 h after placing insects on plants. From this data, the percentage of larvae that bored the stem was calculated. Frass coming out of the stem and visible entry holes were considered as confirmation of larval boring into the stem. Boring success was calculated using the formula:

$$\text{Boring success} = \frac{\text{Number of larvae bored into the stem}}{\text{Total number of larvae released on plant}} * 100$$

In 2009, rice was planted on two dates, June 15th and June 22nd. The plants were infested on August 5th and August 15th, respectively. Observations were recorded after 48 hours. In 2010, rice

was planted on May 5th and the plants were infested on July 3rd. In 2011, rice was planted on March 11th and infested on May 5th.

Lab assays*:* Boring success of *D. saccharalis* on different cultivars was also investigated in a laboratory experiment using cut stems in 2010 and 2011 (Table 3.1). When greenhouse-grown plants reached the late tillering stage, they were brought back to the lab for experiment initiation. A 25-cm stem piece was cut from the base of the primary tiller near the soil line of each plant of each cultivar and placed in glass test tubes (Pyrex, Tewksbury, MA) measuring 20 centimeters in length and 2.5 cm diameter. The end of the stem placed in the tube was sealed using parafilm. The other end was kept outside the test tube and the test tube was sealed using a foam plug. To keep the cut stems fresh, a wet cotton plug was placed on stem ends kept outside the test tube. Experiments were conducted as a RBD with five replications. A block consisted of a test tube rack containing randomly arranged test tubes. In each block there were eight test tubes with cut stems from plants of each cultivar. Ten second instar larvae were released on the side of test tube using a camel hair brush. Observations of numbers of larvae that remained outside the cut stems were taken 24 and 48 h after placing insects inside the glass test tube. From this data, the percentage of larvae that bored the stem was determined as described above. Frass coming out of the stem and a visible entry hole were considered as confirmation of larval boring into the stem.

Data analysis: Data for experiments that evaluated the same set of cultivars were analyzed together**.** Data for the two plantings from 2009 were analyzed together as a replicated RBD using a linear mixed-model in PROC MIXED (SAS institute 1999) with planting and block (planting) as random effects and cultivar as a fixed effect. Data from the 2010 and 2011 greenhouse experiments were analyzed together as replicated RBD with repeated measures using linear mixed model in

PROC MIXED (SAS institute 1999) with year, block(year) and cultivar*block(year) as random effects and time and cultivar as fixed effects. Data from lab experiments were analyzed in a similar manner. Least square means were used for mean separation.

Relative growth rate studies

Greenhouse studies*:* No choice greenhouse studies using intact plants were conducted in 2010 and 2011 to investigate the relative growth rate of *D. saccharalis* on widely grown rice cultivars (Table 3.1). In 2010 and 2011 rice was planted on April 29th and March 11th, respectively. Experiments were conducted as RBD experiments with five replications. The blocks consisted of groups of eight plants, one plant of each cultivar, spatially arranged on a greenhouse bench as described previously in the larval borer success. At the late tillering stage, plants were infested using one second instar *D. saccharalis* larva per plant. The larvae were taken off artificial diet, starved for three hours and weighed prior to release on the stems to obtain an initial weight. Small plastic tubes identical to those used in the boring success experiment were used as cages to confine the insects to individual plants. The tube cages were placed over the primary tiller of each plant and foam plugs were used to seal the top and bottom of the tube cages enclosing the stem. Larvae were recovered after seven days, starved for three hours and weighed (to obtain a final weight). Weight gain and relative growth rates of the larvae were calculated using the formula:

$$\mathrm{RGR} = \frac{\text{Final weight} - \text{Initial weight}}{\left\{\dfrac{\text{Final weight} + \text{Initial weight}}{2}\right\} * \text{Number of days feeding}}$$

(Waldbauer, 1968)

Lab assays: Lab experiments were conducted using cut stems in 2010 and 2011 to further investigate the RGR of *D. saccharalis* larvae on different rice cultivars (Table 3.1). Rice was planted on May 18th and March 11th in 2010 and 2011, respectively. When plants in the greenhouse reached late tillering, they were brought back to the lab for experiment initiation. From the central tiller of each plant of each cultivar two stem pieces were cut, each about 12 cm long. The two cut stems from each plant were placed in the center of a large petri dish (14 cm diameter) lined with wet filter paper to keep the stems fresh. Experiments were conducted as a RBD with five replications. A block was a rack with petri dishes arranged randomly. In each block there were eight petri dishes with cut stems from plants of each cultivar. One second instar *D. saccharalis* larva was released into each petri plate. The larvae had been taken off artificial diet, starved for three hours and weighed (initial weight) prior to release on the stems. The petri plates were then sealed with parafilm to prevent escape of the larvae. The larvae were recovered after seven days. They were starved for three hours and weighed again (final weight). Relative growth rates were calculated as described above.

Data analysis: Data from the 2010 and 2011 greenhouse experiments were analyzed together as a replicated RBD using a linear mixed-model in PROC MIXED (SAS institute 1999) with year and block(year) as random effects and cultivar as a fixed effect. Data from lab experiments were analyzed in a similar manner. Means were separated using Tukey's HSD test (Tukey 1953).

Time until entry into the stem

Greenhouse studies: Experiments were conducted in 2011 and 2012 to investigate the time taken by the larvae to enter into the stems after placement of eggs on plants. In this experiment, two cultivars, 'Cocodrie' and 'XL723,' were used. At the late tillering stage, plants were infested with

egg masses obtained from the laboratory colony. Egg masses were one day old and were laid on wax paper (Reynold's consumer products, Lake Forest, IL). The wax paper with one day old egg masses was cut into small pieces, each having one egg mass. Each egg mass consisted of about 25-30 eggs. One egg mass was attached to a leaf on central tiller of each plant of the two cultivars using a paper clip. The experiment was conducted as a RBD with ten replications. The blocks consisted of two plants, one plant of each cultivar, spatially arranged on a greenhouse bench. After clipping of the egg masses, plants were observed daily until the larvae entered the stems of two cultivars. A visible entry hole and frass coming out of the stem was considered as an end point for larval entry into the stem.

Data analysis: Data for the two years were analyzed together as a replicated RBD using a linear mixed model in PROC MIXED (SAS Institute 1999) with year and block(year) as random effects and cultivar as a fixed effect. Means were separated using Tukey's HSD test (Tukey 1953).

Preference and performance correlation

In 2012, a greenhouse study was conducted to investigate the correlation between oviposition preference and larval performance using the eight cultivars used in 2010-2011 experiments (Table 3.1). Three separate groups of 40 plants, all planted on the same date, were used to simultaneously quantify oviposition preference, larval growth rates and boring success. Each group of 40 plants consisted of five plants each of the eight cultivars. Experiments were initiated when plants reached late tillering stage. All experiments were conducted as a RBD with five replications.

Methods used to quantify larval growth rates and boring success was conducted as described above (greenhouse). The oviposition preference experiment was conducted as a randomized block design with five replications. A cage consisting of a PVC frame

(211×112×122cm) covered with EcoNet B fabric (Ludvig Svensson, Inc., Charlotte, NC) was used as a block (replication). In each cage, one plant of each cultivar was randomly arranged inside the cage. The experiment was a choice study in which insects were given access to eight cultivars. Recently eclosed (< 24 h) adult *D.saccharalis* were selected from the laboratory colony and added to each cage at a density of one male:female pair per plant. Adults were placed in the centers of cages between 1500-1800h and were left in cages for six days. Afterwards, plants were removed and any live adults were discarded. Each plant was transported to the laboratory where the number of egg masses on each plant was recorded.

Data analysis: To study the relationship among preference and performance, data for larval boring success, relative growth rate and oviposition preference were analyzed using PROC CORR (SAS 1999) and Pearson's correlation coefficients between them were used to test the significance of correlation. Correlations were determined based on averages from each cultivar.

Results

1. Field study

There was a significant effect of cultivar on the average number of borer entry/ exit holes per plant ($F_{5,33}$=6.00 P=0.0005) (Figure. 3.1). The greatest number of holes per plant was found in Cocodrie (4.84±0.51 holes per plant) followed closely by Cheniere (4.31±0.40 holes per plant). Number of holes per plant was lowest on Jupiter (2.31±0.41 holes per plant) and CL161 (2.71 ±0.58 holes per plant). Number of holes per plant on Jupiter was significantly different from Cocodrie. Number of holes per plant on Wells and the hybrid XL723 and were intermediate. There was no significant effect of insecticide treatment on number of holes per plant in each cultivar ($F_{1,33}$=0.59 P=0.45).

2. Boring success

Greenhouse studies: In 2009, There was a significant effect of cultivar on larval boring success ($F_{7,63}$=6.72 P<0.0001) (Table 3.2). The greatest number of larvae bored into the stems of Cocodrie

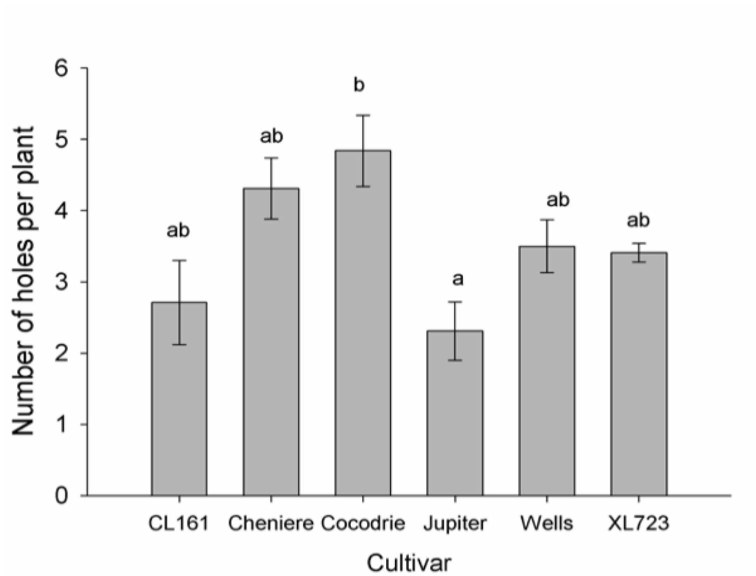

Figure 3.1 Mean (±SE) number of holes per plant of six cultivars in field. Means capped by the same letter do not differ significantly based on Tukey's HSD (p≤0.05)

Table 3.2 Boring success of *D. saccharalis* larvae on different rice cultivars in the greenhouse.

Cultivar	Boring success percentage (Mean ±SE**)	
	2009	(2010, 2011)
Bengal	38.00 b	43.00 ab
CL151	-	44.00 ab
CL161	37.00 b	46.00 ab
Cheniere	50.00 ab	49.00 ab
Cocodrie	67.00 a	55.00 a
Jazzman	-	44.00 ab
Priscila	65.00 a	57.00 a
XL723	43.00 b	36.00 b
Jupiter	54.00 ab	-
XP744	51.00 ab	-

**Least square mean standard error: 6.94 8.87

Means within a column followed by the same lower case letter do not differ significantly.

(67 %) followed closely by Priscilla (65 %). Boring success was lowest on stems of CL161 (37 %) and Bengal (38 %). Boring success on these latter two cultivars was significantly different from Cocodrie and Priscilla. Larvae on the medium grain variety Jupiter, the hybrid XP744 and the long grain Cheniere showed intermediate levels of boring success.

Similar to 2009 studies, cultivar had a significant effect in 2010 and 2011 ($F_{7,71}$=3.78 P<0.002) on larval boring (Table 3.2). The greatest number of larvae bored into the stems of Priscilla (57 %) and Cocodrie (55 %). Larval boring was approximately 36 % higher in Priscilla and Cocodrie compared to XL723, on which larval boring success was lowest at 36 %. All other cultivars were intermediate.

Time had a significant effect on overall larval boring success of larvae ($F_{1,72}$=93.49 P<0.001). More larvae bored the stems at 48 hours (57.5 %) than at 24 hours (36 %) after infestation. The time*cultivar interaction was not significant ($F_{7,72}$=0.92 P<0.49).

Lab studies

The data from cut stem assays conducted in 2010 and 2011 did not reveal any significant

Table 3.3 Boring success of *D. saccharalis* larvae on different rice cultivars in the lab

Cultivar	Boring success percentage (Mean±SE**)
Bengal	46.00 a
CL151	50.00 a
CL161	47.00 a
Cheniere	53.00 a
Cocodrie	63.00 a
Priscilla	60.00 a
XL723	43.00 a
Jazzman	43.00 a

**Least square mean standard error: 7.88

Means within a column followed by the same letter do not differ significantly (p≤0.05)

differences among cultivars for boring success ($F_{7,71}$=1.50 P<0.18) (Table 3.3) but the trends were consistent with the greenhouse studies. Numerically more larvae bored into the stems of Cocodrie (63 per cent) and Priscilla (60 per cent), while lower numbers of larvae bored into the stems of Jazzman and XL723 (43 Per cent).

Similar to greenhouse studies, time had a significant effect ($F_{1,72}$= 110.12 P<0.001) on overall boring success of larvae (data not shown). Approximately 24 per cent more larvae bored into stems at 48 hours than at 24 hours after infestation. The time*cultivar interaction was not significant ($F_{7,72}$=0.62 P<0.75).

Relative growth rate (RGR)

Greenhouse Studies: RGR experiments conducted in 2010 and 2011 revealed a significant effect of cultivar on the RGR of *D. saccharalis* larvae ($F_{7,67}$=3.78 P=0.002) (Table 3.4). Mean RGR of larvae were highest on Cocodrie (0.22 g/g day) followed by Priscilla (0.21 g/g day). RGR were lower on XL723 (0.14 g/g day) and CL161 (0.13 g/g day). Mean RGR of larvae on other cultivars was intermediate. Mean RGR of larvae was approximately 38 per cent higher on Cocodrie than CL161.

Lab Studies: Cut stem assays conducted in the lab during 2010 and 2011 showed trends in RGR of larvae similar to those seen for the greenhouse (Table 3.4). Here also cultivar had a significant effect ($F_{7, 52}$=3.68 P=0.003) on the RGR of larvae. The mean RGR of larvae was highest on Cocodrie (0.21 g/g day) followed closely by Priscilla. These were significantly different from Bengal on which the larvae had lowest RGR (0.12 g/g day). RGR of larvae on Cocodrie and Priscilla were approximately 60 per cent higher relative to Bengal. All the other cultivars were

intermediate. The mean RGR of larvae on Priscilla and Cocodrie was 40-50 per cent higher than XL723 and CL161.

Table 3.4 Relative growth rate (g/g day) of *D. saccharalis* larvae on different rice cultivars in greenhouse and lab studies during 2010 and 2011.

Cultivar	Relative growth rate (Mean±SE**)	
	Greenhouse	Lab
Bengal	0.15 abc	0.12 b
CL151	0.16 abc	0.18 ab
CL161	0.13 c	0.13 ab
Cheniere	0.16 abc	0.20 ab
Cocodrie	0.22 a	0.21 a
Priscilla	0.21 ab	0.21 a
XL723	0.14 bc	0.14 ab
Jazzman	0.17abc	0.19 ab

**Least square mean standard error: 0.304 0.028
Means within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

Preference and performance correlations

A significant positive correlation was found between the two measures of larval performance, larval boring success and relative growth rate of larvae (r= 0.73 P=0.04) (Table 3.5). The relationship between oviposition preference and boring success of *D. saccharalis* was found to be significantly positive (r=0.73 P=0.04). Likewise, a strong and significant positive correlation was observed between oviposition behavior and RGR of larvae (r=0.94 P=0.0004).

Table 3.5 Correlation between oviposition preference and larval performance during 2012 greenhouse study

	Pearson Correlation Coefficient	
	Boring success	Oviposition preference
RGR	r=0.844 P=0.0085	r=0.934 P=0.0007
Boring success	1.0000	r=0.802 P=0.017

Time until entry into the stem

Larvae took significantly more time to enter into the stems of XL723 than Cocodrie ($F_{1, 19}$=25.86 P<0.0001) (Figure 3.2). After attaching the egg masses to plants, the larvae took about 8.9 days to enter into the stems of Cocodrie while the larvae took about 10.4 days to enter into the stems of XL723.

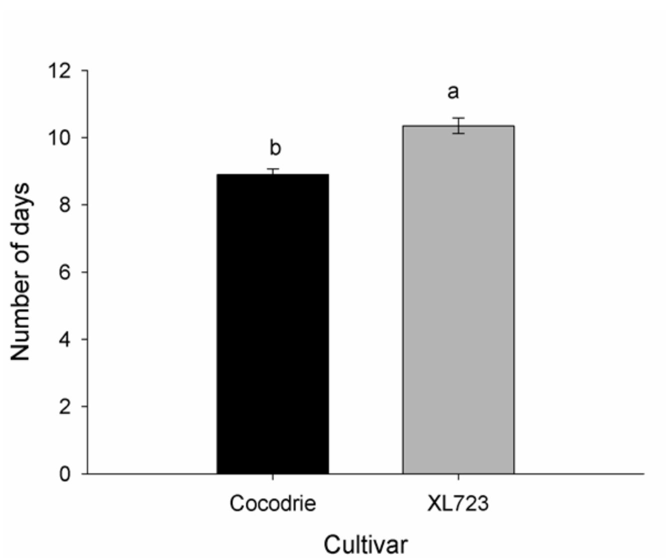

Figure 3.2 Mean (±SE) number of days taken by *D. saccharalis* larvae to enter into the stems of two cultivars Cocodrie and XL723 in greenhouse studies.

Discussion

Stem borers are among the most important pests of rice globally and are becoming increasingly important pests of rice in the southeastern United States. This study was conducted to assess the potential for plant resistance to be used as a part of the management program for stem borers in Louisiana rice. The cultivars used in these experiments collectively represented approximately 75% of the rice acreage in Louisiana in 2009-2012. Variation in resistance to *D. saccharalis* among these eight cultivars was moderately strong. In the larval performance experiments, reductions in boring success and relative growth rate of larvae on resistant cultivars ranged from 30-50 % relative to the susceptible cultivars. Similarly, the oviposition choice studies in the greenhouse showed that the females distinctly preferred to lay more eggs on Priscilla and Cocodrie compared to the hybrid XL723 and the Clearfield cultivars. Oviposition preference was 50-60 % lower on resistant cultivars. In addition, resistance was fairly consistent across experiments. Priscilla and Cocodrie were always among the most susceptible cultivars, while the hybrid XL723, the medium grain Bengal and the herbicide tolerant long grain CL161 were always among the resistant cultivars. Furthermore, there was a good correspondence among measures of larval performance and oviposition preference. Significant positive correlations were observed among boring success, relative growth rate and oviposition preference. Finally, results in lab and greenhouse extended to the field, where Cocodrie and Cheniere were the most injured cultivars while CL161 and the medium grain Jupiter were least injured in terms of average number of stem borer entry/exit holes per plant. These results suggest that cultivar resistance has the potential to contribute to the management program for stem borers at present.

Host plant resistance has been a major focus of stem borer management studies in Asia. Variation in stem borer resistance in Indian and Japanese cultivars was noted as long as the 1950's

and 1960's (Israel 1967, Matsuo 1952). In the late 1960s, Pathak (1969) and other scientists at International Rice Research Institute (IRRI) screened over 10,000 rice lines for resistance to *Chilo suppressalis* (Walker) and identified 20 cultivars with usable levels of resistance. In their studies, resistance was manifested by both reduced oviposition and reduced larval growth and survival on resistant lines. Later in the 1970s, moderate resistance was introduced into a large number of cultivars released by IRRI (Khush 1989). There have also been a limited number of studies on *D. saccharalis* resistance in Louisiana rice cultivars. Oliver and Gifford (1972) conducted studies on selected lines from the world rice collection and reported fewer larvae and less infestation in some rice lines when compared to a commercial cultivar "Saturn" in small plot trials. Larvae gained approximately 58% more weight on "Saturn" compared to a resistant line. However, the cultivars screened by Oliver and Gifford (1972) are now obsolete. More recently, Way et al (2006) conducted a study to assess the resistance of rice cultivars against sugarcane borer and the Mexican rice borer and they observed significant differences among cultivars in terms of injury and yield losses.

Levels of stem borer resistance identified in prior studies in Asia and North America has ranged from low to moderate and no cultivars identified in previous studies have been completely resistant to stem borers (Chandler 1967, Khush 1989). Similarly, only moderate levels of resistance were found in the present study. Nonetheless, levels of cultivar resistance to stem borers have proven sufficient to contribute to borer management programs and breeding programs.

Significant positive correlations observed among the two measures of larval performance and oviposition preference suggest the operation of a common basis for reduced oviposition and larval growth of *D. saccharalis*. Pathak et al (1971) reported that susceptibility of most rice cultivars appeared to be positively correlated with oviposition preference of moths. Many

morphological, anatomical, physiological and biochemical factors have been associated with stem borer resistance. Apparently, not a single character but several plant characters such as plant height, stem diameter, length and width of flag leaf, tight leaf sheaths, narrow stem lumen, plant silicon content and heavily sclerotized stems influence stem borer resistance (Chaudhary et al 1984). Seko and Kato (1950) reported that stem borer larvae encountered variable levels of difficulty while boring into the stems of different cultivars and this led to variation in susceptibility of cultivars. High mortality of *C. suppressalis* larvae on a highly resistant wild species of rice *O. ridleyi* was apparently due to difficulty of larval boring into the heavily sclerotized stems (Van and Guan 1959). Patanakamjorn and Pathak (1967) observed that 95 per cent of the larvae migrated between the leaf sheath and stem within 48 hours after hatching and established more easily on loose sheathed cultivars compared to cultivars in which the leaf sheath was tightly appressed to the stem.

The correlation between oviposition preference and larval performance in this study are consistent with the optimal oviposition theory (Jaenika 1978), according to which female oviposition preference should correlate with the host suitability for offspring performance. Choice of a suitable oviposition site is crucial for lepidopterous insects, as the neonates of many species are relatively immobile and have to feed on the same plants on which eggs are laid (Singer 1986). A meta-analysis of preference-performance relationships in phytophagous insects conducted by Gripenberg et al (2010) clearly supported the preference performance hypothesis (PPH) i.e., offspring tend to perform better on plants preferred for oviposition and females lay more eggs on plant types conducive to offspring performance.

Gripenberg et al (2010) discussed possible mechanisms promoting the formation over evolutionary time of a positive preference- performance relationship. They stated that limited

offspring mobility can be considered a potentially important selective factor promoting female preference for good quality hosts (Craig and Itami 2008, Feeny et al. 1983, Thompson 1988). The larvae of *D. saccharalis* have relatively limited mobility and feed on or near the plant where they hatch before they move to other plants (Holloway 1928). Another factor responsible for positive preference- performance relationship is aggregation of offspring (Gripenberg et al 2010). Selection of a high quality host should be more important for species that lay their eggs in clusters because a single poor decision could lead to a larger loss of progeny in these species than in those that lay their eggs singly (Hopper 1999, Mangel 1987). *D. saccharalis* females also lay eggs in clusters. Finally, for female insects that have the potential to feed as adults, fecundity may be less dependent on resources acquired at previous stages (Wheeler 1996, Jervis et al 2008), whereas for female insects that do not feed, fecundity is dependent on the larval resources. This may be considered as another possible explanation for the positive correlation between preference and performance for *D. saccharalis*.

Knowledge of *D. saccharalis* resistant genotypes could also be useful for developing management strategies against Mexican rice borer, an invasive stem-boring species that has recently moved into Texas and is spreading eastward. This is because past studies have revealed "cross resistance" between different stem borer species on resistant cultivars. At IRRI (1970), resistance of a common set of cultivars against four different species of stem bores was studied and similar levels of resistance among all cultivars against the four different stem borer species was observed. Das (1976) reported that some lines and cultivars resistant to *Chilo suppresalis* were also resistant to some other species of stem borers. Oliver and Gifford (1972) observed that larval growth and development of two stem borer species varied on different rice cultivars but larval response to different rice cultivars was similar for both *C. plejadellus* Zincken and *D. saccharalis*.

Zhou et al (2010) demonstrated cross resistance between *D. saccharalis* and *E. loftini* in sugarcane genotypes. Sugarcane genotypes resistant to *D. saccharalis* were 40% less likely to be bored by *E. loftini*. Consistent with these studies, Way et al (2006) conducted a study to assess the resistance of rice cultivars in an area in which both sugarcane borers and Mexican rice borers were present. In their study, Priscilla was consistently the most susceptible cultivar based on the whiteheads per square meter while several hybrid cultivars were among the cultivars with lowest numbers of whiteheads per square meter. They observed similar levels of relative susceptibility among rice cultivars planted across years and suggested that mechanisms of resistance could be comparable for both borer species.

Currently, no sound management program is in place for stem borers in Louisiana. With the increasing impact of stem borers including the Mexican rice borer on rice in the southeastern United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics, including host plant resistance. Integrated pest management tactics that are more durable and easily applicable should be developed. Host plant resistance and cultural control are now the main tactics under development for stem borer management in China (Hao *et al*., 2008). Cultivar resistance has been considered as an economical, convenient, durable, non-hazardous and built-in control measure. It is also compatible with other management tactics. Therefore the use and development of stem borer resistant cultivars should be emphasized.

Farmers in southwest Louisiana may benefit by choosing high yielding resistant cultivars. Assuming a similar cross resistance in rice, Clearfield and hybrid cultivars could be recommended for cultivation in areas where *E. loftini* is invading and is likely to be a problem. Similar levels of resistance to both species have been identified in sugarcane cultivars in Texas and Louisiana (Reay Jones et al 2003). Thus a widespread use of stem borer resistant cultivars of the major host plants

may help suppress the pest population below economic injury levels and to manage pest populations on areawide basis. In addition, use of resistant cultivars may benefit management indirectly by delaying larval entry into the stems and thereby increasing the window of time during which larvae are susceptible to insecticides. The resistant cultivars identified herein could also serve as a source of resistance in breeding programs for resistance against stem borers and as a tool for better understanding of mechanisms of cultivar resistance. Future studies may be carried out to investigate the preference-performance relationship in field under different environmental constraints and combining cultivar resistance with other management strategies that include insecticide seed treatments (Dermacor) and soil silicon amendments.

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CHAPTER 4: EFFECT OF SILICON SOIL AMENDMENTS ON THE PERFORMANCE OF SUGARCANE BORER, *DIATRAEA SACCHARALIS* (LEPIDOPTERA: CRAMBIDAE) ON RICE

Introduction

Stem borers are one of the most important groups of rice (*Oryza sativa* L.) pests worldwide (Akinsola 1984). Borers attack rice plants from seedling to maturity and are one of the reasons for low yields in the rice growing countries of Africa and Asia (Akinsola 1984). Stem borers attacking rice are mostly Lepidopterans belonging to the families Crambidae and Noctuidae (Pathak and Khan 1994). The life cycles and damage caused by these boring Lepidopterans are similar. The damaging stages of stem borers, the larvae, are internal feeders. After hatching, the young larvae move to between the leaf sheath and stem where they feed inside the leaf sheath. Initial feeding by the larvae in the leaf sheath causes broad longitudinal reddish brown lesions at the feeding sites. Shortly thereafter, larvae bore into the stem and feed internally. At the vegetative stage of rice plant growth, feeding by stem borer larvae results in "deadhearts", in which the young tillers and the leaves of the tillers die. During the reproductive stage, injury to tillers can destroy the panicles resulting in "whiteheads". Extensive feeding can also lead to lodging of rice plants (Pathak, 1968; Holloway, 1928; Castro *et al.*, 2004). If injury occurs at an early stage, borer-injured plants can recover partially by production of new tillers (Bondong & Litsinger, 2005, Lv *et al.*, 2008).

Stem borer species that have been reported to infest rice in southern United States include the rice stalk borer; *Chilo plejadellus* Zincken, and the sugarcane borer, *Diatraea saccharalis* (F.). The sugarcane borer is a major agronomic pest in the southeastern U.S. Holloway *et al.* (1928) reported more than twenty host plants for the sugarcane borer. In addition to sugarcane (*Saccharum officinarum* L.), it is an economically important pest of corn (*Zea mays* L.), rice, and

sweet sorghum (*Sorghum bicolor* L. Moench) (Roe *et al.*, 1981). In recent years, rice farmers in the southern U.S have experienced increased problems with *D. saccharalis*. In 2002, for example, approximately 1214 ha of rice in Concordia parish in central Louisiana were infested with *D. saccharalis,* damaging 70 to 95 percent of the rice crop on some farms (Castro *et al.*, 2004). Moreover, another stem-boring species, the Mexican rice borer, has invaded Louisiana (Hummel *et al*., 2010) and has the potential for inflicting significant economic losses (Reay-Jones *et al*., 2008).

With the increasing impact of stem borers on rice in the southeastern United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics, including host plant resistance. Chemical control is the most widely used management tactic but it is not very cost-effective. Insecticides are expensive and their use can have adverse environmental effects on non-target organisms, both terrestrial and aquatic (Chelliah &Bharathi, 1994, Litsinger et al. 2005). Moreover, the feeding habits of stem borers shelter them from non-systemic insecticides and thereby reduce their effectiveness. Likewise, biological control has not been found feasible to control stem borers in rice in temperate climates such as the U.S (Lv *et al.*, 2011). Integrated pest management tactics which are more durable and easily applicable should be developed. Host plant resistance and cultural control are now the main tactics under development for stem borer management in China (Hao *et al*., 2008).

Rice is a typical silicon (Si)-accumulating graminaceous species (Takahashi *et al.,* 1990; Ma *et al.,* 2006; Zhao *et al*., 2010). Although Si is not considered an essential element, Si-accumulating graminaceous plants grown without Si exhibit a range of abnormalities in growth, development and reproduction (Yoshida, 1975; Takahashi, 1995). Si uptake leads to formation of a thick silicate epidermal cell layer that can make the plants less susceptible to biotic and abiotic

stresses (Ma 2004), including insect pests like borers, hoppers and mites (Chandramani *et al.,* 2010; Djamin & Pathak 1967). Si content in rice plants varies with plant age. Older plants and leaves typically have higher Si content than younger plants and leaves (Ishizuka, 1964).

Augmentation of soil using Si based fertilizer is one crop management tactic that has proven beneficial for rice production, especially on soils deemed to be low or limiting in this element. Beneficial effects include yield increases and improved disease and insect control (Savant *et al.,* 1997; Alvarez & Datnoff, 2001; Ma *et al*., 2001). A number of studies have shown positive correlations between increased Si content in plants and enhanced insect resistance (Djamin & Pathak, 1967; Moore, 1984; Salim & Saxena, 1992; Sharma & Chatterji,1971). Based on these previous studies suggesting a role for Si in resistance towards other stem boring species, Si amendments were expected to increase the resistance of rice to *D. saccharalis.* The purpose of this study was to evaluate the effect of Si on the relative growth rates and boring success of *D. saccharalis* larvae in a susceptible and moderately resistant rice cultivar. This is the first study conducted on the effect of Si on *D. saccharalis* in rice.

Materials and Methods

Plant growth and Si treatment: Plants for all experiments were grown in a greenhouse located on the campus of Louisiana State University, Baton Rouge. Two cultivars, 'Cocodrie' and 'XL723,' were used. Cocodrie is a widely grown, conventional long-grain cultivar and XL723 is a long-grain hybrid (2003 proprietary hybrid, Rice-Tec, Alvin, TX). Prior experiments have shown Cocodrie to be susceptible to *D. saccharalis* while XL723 has been found to be moderately resistant (Sidhu and Stout, unpublished manuscript). The soil mix used for planting consisted of two parts sterilized top soil (Entisol), one part peat moss and one part sand. Analysis for Si

content of the soil mix using acetic acid extraction (Soil Fertility lab, School of Plant, Environment and Soil Sciences, LSU Agricultural Center) showed the Si content to be approximately 24.95ppm. Seeds were planted in the soil mix in 15cm diameter pots (3.8L). Plants were maintained under greenhouse conditions with ambient lighting at approximately 29°C- 33°C. At the time of planting, approximately 1.2g of 19:5:8 controlled release fertilizer (Osmocote, Scotts Miracle-Gro, Marysville, OH) was added to the soil. Plants were thinned to a density of one plant per pot five to seven days after planting. The designation of rice plant stages followed the system outlined by Counce et al (2000). All experiments were conducted when plants were at the late tillering stage (50-55 days after planting).

At the two leaf growth stage of rice plants, plants assigned to the Si augmentation treatment were treated by adding calcium silicate (slag) (Calcium Silicates Corporation, Columbia, TN) at 4 m^3 tons ha^{-1} (7.3g per pot) directly on the soil surface in the pots. This rate was chosen because it represents the highest field rate that could be potentially used economically in the field and would potentially have the maximum Si response (Datnoff 1991).

Insects: *D. saccharalis* larvae used in experiments were obtained from a colony maintained continuously in the laboratory at Louisiana State University following the methods of Martinez et al (1988). The colony originated from larvae collected in rice fields near Crowley, LA, in 2005. Larvae were reared in 29.5 ml Solo soufflé cups (AceMart Restaurant Supply, San Antonio, TX) on sugarcane borer artificial diet (Southland Products, Lake Village, AR). Pupae were sexed according to Butt and Cantu (1962) and equal numbers of males and females were placed into three liter plastic buckets with wax paper as a substrate for oviposition. Adults were provided with a 1:1 mixture of honey and beer (Milwaukee’s Best Light, Miller Brewing Co., Milwaukee, WI) and distilled water. Eggs were put into eight cell trays for hatching. When the eggs hatched,

neonates were placed on artificial diet and reared until use. The colony was maintained under controlled environmental conditions (14L;10D, 28°C ± 2°C, 38% R.H. ± 2% R.H.). Insects collected from rice fields were added annually to the colony to maintain genetic variability.

Larval Boring Success

Greenhouse studies: No choice greenhouse studies using intact plants were conducted in 2011 and 2012 to assess the boring success of larvae on Si-treated and non-treated plants. Boring success was defined as the proportion of second instar larvae entering the stems within 72 h of being placed on plants. Experiments were conducted as randomized block design (RBD) experiments with five replications. Blocks consisted of groups of four plants (one Si-treated and one non-treated plant of each of the two cultivars) spatially arranged on a greenhouse bench. At the late tillering stage, plants were infested using five second instar *D. saccharalis* larvae per plant. Small plastic tube cages were used to confine insects on the plants. These tubes were 15 cm long and 2.5 cm in diameter. Tubes were placed over the primary tiller of each plant and foam plugs were used to seal the top and bottom of the tube cages enclosing the stem. Observations of numbers of larvae that remained outside the stems of the plants were taken 72 h after placing insects on plants. From this data, the percentage of larvae that bored into the stem was calculated. Frass coming out of the stem and visible entry holes were considered as confirmation of larval boring into the stem. Boring success was calculated using the formula:

$$\text{Boring success} = \frac{\text{Number of larvae bored into the stem}}{\text{Total number of larvae released on plant}} * 100$$

Lab assays: The effect of Si on boring success of *D. saccharalis* was also investigated in a laboratory experiment using cut stems in 2011. When greenhouse-grown plants reached the late

tillering stage, they were brought back to the lab for experiment initiation. A 25 cm stem piece was cut from the base of the primary tiller near the soil line of each plant of each variety and placed in glass test tubes measuring 20 centimeters in length and 2.5 cm diameter. The end of the stem placed in the tube was sealed using parafilm. The other end was kept outside the test tube and the test tube was sealed using a foam plug. To keep the cut stems fresh, a wet cotton plug was placed on stem end kept outside the test tube. The experiment was conducted as a RBD with five replications. A block consisted of a test tube rack containing randomly arranged test tubes. In each block there were four test tubes with cut stems from plants of each cultivar, one Si treated and one non-treated control. Infestations were done using five first instar *D. saccharalis* larvae per test tube. The larvae were released on the side of test tube using a camel hair brush. Observations of numbers of larvae that remained outside the cut stems were taken 72 h after placing insects inside the glass test tube. From this data, the percentage of larvae that bored the stem was determined as described above. Frass coming out of the stem and a visible entry hole were considered as confirmation of larval boring into the stem.

Relative growth rate

Greenhouse studies: No-choice greenhouse studies using intact plants were conducted in 2011 and 2012 to investigate the relative growth rate (RGR) of *D. saccharalis* larvae on Si-treated and non-treated plants of the two cultivars. Experiments were conducted as RBD experiments with five replications. The blocks consisted of groups of four plants spatially arranged on a greenhouse bench as described above. When the plants reached late tillering stage, infestations were done using one second instar *D. saccharalis* larva per plant. The larvae were taken off artificial diet, starved for three hours and weighed prior to release on the stems to obtain an initial weight. Small plastic tubes identical to those used in the boring success experiment were used as cages to

confine the insects to individual plants. The tube cages were placed over the primary tiller of each plant and foam plugs were used to seal the top and bottom of the tube cages enclosing the stem. Larvae were recovered after seven days, starved for three hours and weighed (final weight). Weight gain and relative growth rates of the larvae were calculated using the formula:

$$\mathrm{RGR} = \frac{\text{Final weight} - \text{Initial weight}}{\left\{\frac{\text{Final weight} + \text{Initial weight}}{2}\right\} * \text{Number of days feeding}}$$

(Waldbauer, 1968)

Lab assays*:* Lab experiments were conducted using cut stems in 2011 to further investigate the effect of Si on RGR of *D. saccharalis*. When plants in the greenhouse reached late tillering, they were brought back to the lab for setting up the experiment. From the central tiller of each plant, two stem pieces were cut, each about 12 cm long. The two cut stems from each plant were placed in the center of a large petri dish (14 cm diameter) lined with wet filter paper to keep the stems fresh. The experiment was conducted as a RBD with five replications. A block was a rack with petri dishes arranged randomly. In each block there were four petri dishes with cut stems from plants of each cultivar (Si treated and non-treated). One second instar *D. saccharalis* larva was released into each petri plate. The larvae had been taken off artificial diet, starved for three hours and weighed (initial weight) prior to release on the stems. The petri plates were then sealed with parafilm to prevent escape of the larvae. The larvae were recovered after seven days. They were starved for three hours and weighed again (final weight). Relative growth rates were calculated as described above.

Si content of plants

In 2012, an additional set of plants was grown in the greenhouse for plant Si analysis. These plants were treated and maintained under conditions identical to those described above. When the plants reached late tillering stage, Si treated and non-treated plants were cut at the soil line and entire plants were sent to the Department of Agronomy (School of Plant, Environment and Soil Sciences) for estimation of plant Si content. Plant tissue Si analysis was done following a two-phase wet-digestion procedure for Si extraction and Molybdenum Blue Colorimetry method for determination of Si concentrations in plant samples as described by Joseph and Breitenbeck (2010).

Data analysis: Data from lab studies were analyzed as a factorial RBD experiment with block as a random effect and treatment and variety as fixed effects using a mixed model analysis of variance in PROC GLIMMIX (SAS 2006). Data from greenhouse studies in 2011 and 2012 were analyzed together as replicated RBD factorial with year and block as random effects and treatment and variety as fixed effects using a mixed model analysis of variance in PROC GLIMMIX (SAS 2006).

Data for Si from the Si analysis were analyzed as a factorial RBD experiment with block as a random effect and treatment and variety as fixed effects using a mixed model analysis of variance PROC GLIMMIX (SAS 2006).

Results

1. **Boring Success**

Greenhouse studies*:* In the greenhouse, the percentage of 2nd instar larvae that bored into rice stems within 72 h differed significantly by Si treatment ($F_{1,27}$=40.05 P<0.0001) but not cultivar

($F_{1,27}$=0.43 P=0.518) (Figure. 4.1). The cultivar*Si interaction was also not significant ($F_{1,27}$=0.43 P=0.518). The percentage of larvae boring into rice stems was reduced by approximately 40% on Si treated plants of each cultivar.

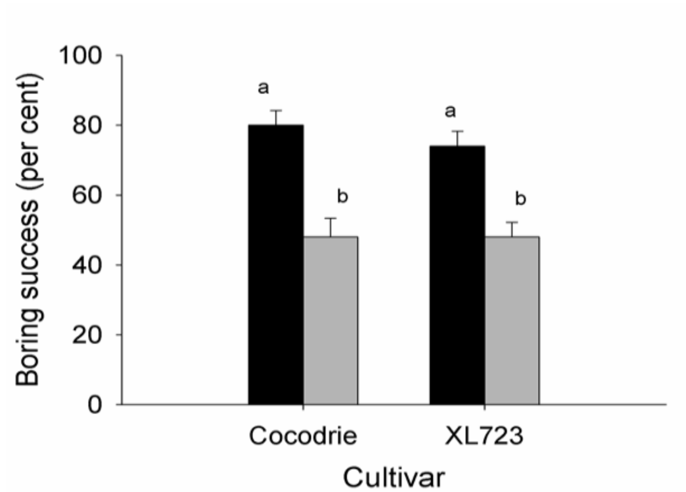

Figure 4. 1 Mean (±SE) larval boring success of *D. saccharalis* larvae on Si treated and un-treated plants of two rice cultivars in GH (2011, 2012). ■ Un-treated ■ Si treated.

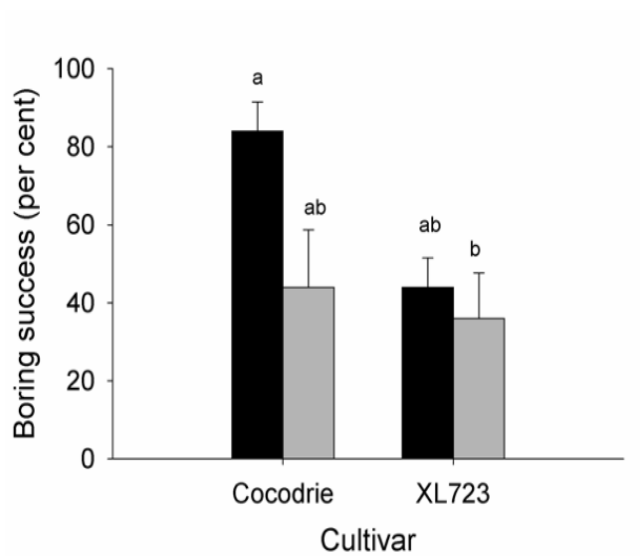

Figure 4. 2 Mean (±SE) larval boring success percentage of *D. saccharalis* larvae on Si treated and un-treated plants of two rice cultivars in lab 2011. ■ Un-treated ■ Si treated

Lab Studies*:* Cut stem assays revealed similar effects of Si on boring success of larvae (Figure 4.2). Significant differences among Si treated and non-treated plants were observed ($F_{1,16}$=4.97 P=0.040). Cultivar also affected boring success ($F_{1,16}$=4.97 P=0.040) as greater numbers of larvae bored into the stems of Cocodrie (64 %) than XL723 (40 %). The cultivar*Si interaction was not significant ($F_{1,16}$=2.21 P=0.157). For Si treated Cocodrie plants, boring success was reduced by 47%, while for XL723 boring success was reduced by 18%.

Relative growth rate

Greenhouse studies: Relative growth rates of larvae recovered from Si treated and non-treated plants after seven days were significantly different ($F_{1,27}$=12.48 P=0.002). RGR's were significantly lower for the Si treated plants (Figure 4.3). RGR's did not differ significantly among cultivars ($F_{1,27}$=0.44 P=0.514). The Cultivar*Si treatment interaction was also not statistically significant ($F_{1,27}$=2.62 P=0.117) although there was a trend

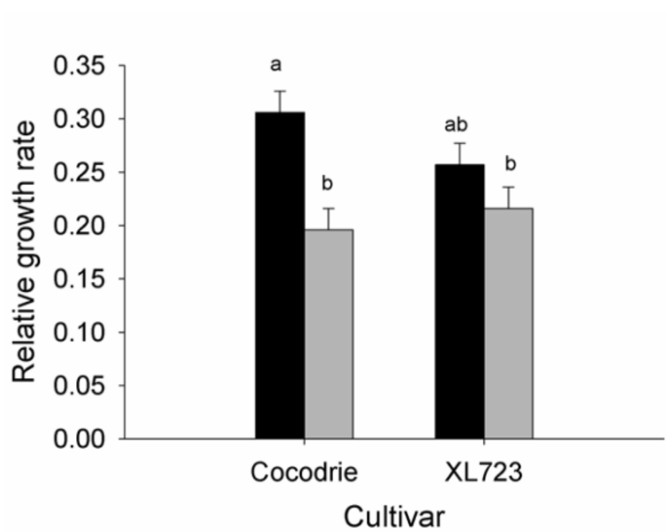

Figure 4.3 Mean (±SE) relative growth rate of *D. saccharalis* larvae on Si treated and un-treated plants of two rice cultivars in GH (2011, 2012). ■ Un-treated ■ Si treated.

towards greater reduction in RGR on the Si treated plants. RGR's were reduced by 36 % for Si treated Cocodrie plants and approximately16 % for the hybrid XL723.

Lab Studies: Results from the RGR assays conducted in the lab were similar to those from the greenhouse studies. RGRs of larvae were significantly lower ($F_{1,16}$=9.47 P=0.007) on the Si treated plants than on the non-treated plants. In the Si treated plants RGR's of the larvae recovered after seven days were approximately 12 % lower on Si-treated Cocodrie plants and 4% lower on Si treated XL723 (Figure 4.4). There was no significant effect of cultivar ($F_{1,16}$=0.35 P=0.563), and the cultivar*Si treatment interaction was also not significant ($F_{1,16}$=1.73 P=0.207).

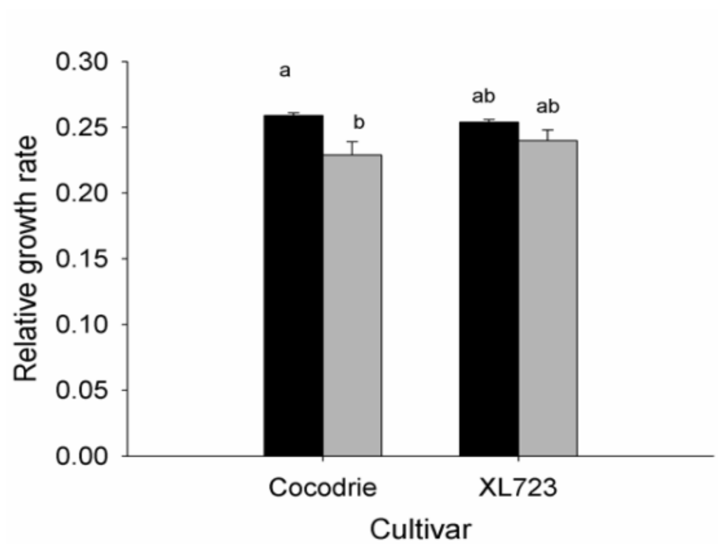

Figure 4.4 Mean (±SE) relative growth rate of *D. saccharalis* larvae on Si treated and un-treated plants of two rice cultivars in Lab 2011. ■ Un-treated ■ Si treated.

Si content in Rice stalks

Amendment of soils with calcium silicate in the greenhouse increased the Si content in rice plants (Figure 4.5). Si content of treated plants was significantly higher than non-treated plants (F=13.70 df=1, 6 P=0.010). There was no significant effect of cultivar ($F_{1,6}$=1.52 P=0.2634) and the cultivar*Si treatment interaction was also not statistically significant. Treated plants had 32 and 17% more Si in Cocodrie and XL723, respectively.

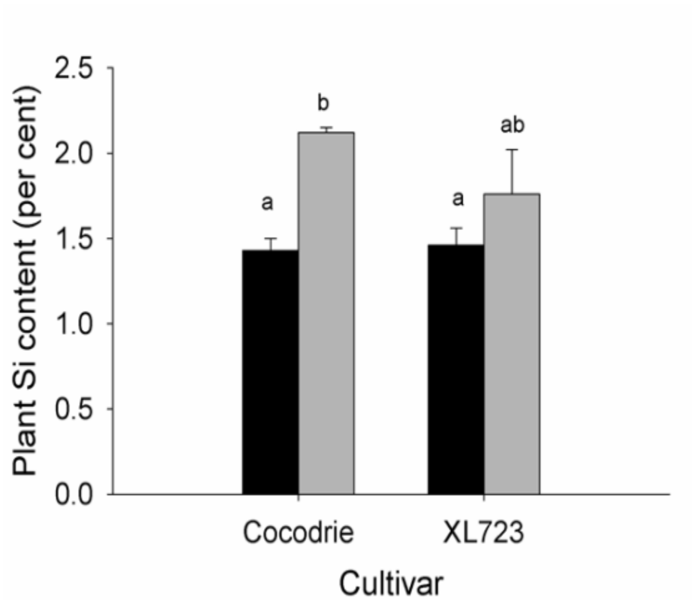

Figure 4.5 Mean (±SE) silicon content of treated and un-treated plants of two rice cultivars. ■ Un-treated ■ Si treated.

Discussion

The stem borers *D. saccharalis* and *C. plejadellus* have historically been considered important insect pests in Louisiana rice (Douglas & Ingram 1942; Oliver *et al*., 1972), and serious infestations of these insects have been reported over the last decade in Louisiana (Castro *et al.*, 2004; MJS personal observartion). Moreover, another invasive stem borer species, *E.*

loftini, has now moved through the Texas rice belt into Louisiana as predicted by Reay-Jones *et al.* (2008). This species was first found in 2008 from two pheromone traps in Louisiana, approximately 8 km from a rice field near Texas border (Hummel *et al.*, 2010). Reay-Jones *et al*. (2008) predicted an annual loss of up to $45 million by MRB, assuming the entire rice industry is infested by this pest by 2035. Despite the importance of stem borers in the past and in the future, there is currently no sound management program for stem borers in Louisiana. This present study was conducted to investigate the potential of Si soil amendments to increase rice resistance to *D. saccharalis*. Results from the present study showed that Si incorporation into soil led to an increase in levels of Si in plant tissues and reduced performance of *D. saccharalis* larvae as manifested by reduced boring success of larvae into the stems of rice plants and reduced relative growth rates of larvae feeding in rice stems.

Incorporation of Si into the soil led to an uptake of Si and an increase in Si tissue concentrations in both rice cultivars. Soil Si augmentation increased the Si content in the plant tissues by approximately 32 and 17% in Cocodrie and XL723 respectively. Levels of Si in leaves and stems are comparable to levels reported by Hou and Han (2010) in Chinese cultivars. In their study, plant Si content increased approximately 15-20 % in susceptible cultivar and 15- 24 % in a resistant cultivar following soil augmentation. Plant Si content in the present study was compared to those reported in other studies. Djamin & Pathak (1967) investigated cultivar differences in Si content and borer susceptibility of 20 varieties. They found that Si content of these varieties ranged from 4.5 % in a susceptible cultivar to 6.49 % in a resistant cultivar. Datnoff et al (1997) evaluated ten different genotypes for Si accumulation and brown spot development on a low Si soil fertilized with 0 and 2 Mg Si ha^{-}. Si content in different genotypes varied from 3.4 - 4.9%. Si augmentation resulted in approximately 38-60 % increase in the mean percent silicon

concentration of different rice cultivars. Si content in rice tissues is influenced by a number of factors including differential uptake in different cultivars, method and type of Si source used and methods used for analysis of plant Si content (Ma *et al.,* 2007; Deren 2001; Datnoff *et al.,* 1997; Moraes *et al*., 2005; Chandramani *et al*., 2010; Kraska and Breitenbeck 2010).

There is a long history of studies that support a role for Si in rice resistance to stem-boring Lepidopterans. The first study on the role of Si in plant resistance to insects was conducted by Sasamoto (1953) on rice stem borer; *Chilo simplex* (Reynolds *et al.,* 2009). A number of subsequent studies demonstrated the role of plant Si in defense against insect pests. Ukwungwu & Odebiyi (1985) recorded a negative correlation between percent Si content in different rice cultivars and the percentage of stems bored by the African striped borer, *Chilo zacconius* Bleszynski (Lepidoptera: Pyraidae), and the number of living larvae per plant. Panda *et al.* (1975) reported that larvae of yellow rice borer, *Scirpophaga incertullas* Walker, were unable to attack rice plants because of the high Si content of their stems. Sasamoto (1958, 1960 & 1961) reported that *Chilo suppresalis* larvae preferred to feed in rice plants with low Si content as compared to plants with high Si content. Nakano et al (1961) found severe rice stem borer infestations in some rice fields where plant available Si in soil was low. Application of calcium silicate decreased both insect infestation and populations in those fields. Ma & Takahashi (2002) conducted petri dish trials and observed a negative correlation between Si content of rice plants and the number of larvae that bored into the stems and the amount of feces.

Consistent with these previous studies, the experiments reported here demonstrate, for the first time, increases in rice resistance to *D. saccharalis* in U.S rice cultivars as a result of soil Si amendment. The positive effect of Si on rice resistance was observed in both greenhouse and lab studies using two measures of resistance, larval boring success and relative growth rate in two

cultivars. Soil Si amendment led to a significant reduction in both RGR's and boring success of larvae on Si treated plants. Although the increases in plant Si content did not significantly differ among the two cultivars, a stronger increase in resistance was observed in the more susceptible cultivar, Cocodrie compared to the moderately resistant XL723. Thus this study was a robust demonstration of the potential for Si to increase resistance to stem borers in U.S rice.

Prior studies have also shown reductions in both boring success and RGR in Si treated plants. Keeping and Meyer (2006) observed a reduction in damage and performance of *Eldana saccharaina* on Si treated sugarcane plants of susceptible and resistant cultivars. They indicated that susceptible cultivars benefit more from Si augmentation. Kvedras & Keeping (2007) found that Si delayed the penetration of sugarcane stalks by *E. saccharina*. Their results were supported by the fact that Si treated plants had increased Si content in the stalk epidermis. Djamin & Pathak (1967) demonstrated that high Si content in the rice plant interfered with feeding and boring of *C. suppresalis* larvae. Likewise, Hou and Han (2010) observed a significant reduction in weight gain by Asiatic rice borer on Si treated rice plants as compared to un-treated plants. Massey and Hartley (2009) observed a reduction in growth rate of *Spodoptera exempta* feeding on Si rich diets and the effect was more pronounced when the larvae were exposed to Si rich diets for a longer duration.

The mechanisms by which Si soil amendments increase the resistance of plants to insects are not fully understood (Kvedaras &Keeping 2007). The most widely cited potential mechanism is a reduction in insect growth and reproduction due to reduced feeding and tissue digestibility resulting from increased hardness and abrasiveness of plant tissues (Kaufman *et al.*, 1985; Ma *et al*., 2001; Massey *et al*., 2006; Massey & Hartley, 2009). Si is deposited in the epidermal layer to form a cuticle- silica double layer (Ma & Takahashi, 2002). Accumulated monosilicic acid

polymerizes into polysilicic acid and then transforms to amorphous silica, which forms a thickened Si-cellulose membrane. By this means, a double cuticular Si layer protects and mechanically strengthens plants. Si also might form complexes with organic compounds in the cell walls of epidermal cells, therefore increasing their resistance to degradation by enzymes released by fungi (Datnoff et al., 2007). Hou and Han (2010) proposed that lower feeding damage on Si treated plants may result from the improper digestion of Si treated rice tissue. The presence of Si in the plants can also increase the bulk density of diet such that the insects are unable to ingest sufficient quantities of nutrients and water (Panda & Khush, 1995). Pathak *et al.* (1971) observed that high plant Si content in rice plants interferes with larval feeding and the larvae feeding on a resistant rice variety (high Si content) have worn mandibles and exhibit low feeding efficiency. Larvae were unable to bore into the stems and suffered higher mortality on varieties with higher Si compared to varieties with low Si content.

In addition, a growing body of evidence indicates a role for soluble Si in inducing plant chemical defenses (Datnoff *et al.,* 2007). The effect of Si on plant resistance to disease (and perhaps insects) is considered to be partly due to expression of pathogenesis-induced host defense responses (Datnoff *et al.*, 2007). Research also points to the role of Si in plants as being active since phenolic compounds, phytolexins, glucanases, peroxidases and PR-1 transcripts were all found to be associated with limited colonization by the rice blast pathogen in epidermal cells of Si treated plants. Recently, a number of pathogenicity or stress-related genes were found to be either up- or down-regulated by Si (Brunings *et al*., 2009). These responses at both the physiological and molecular level suggest that Si might be a signal for priming/inducing defense reactions to plant diseases (Chain *et al*., 2009; Ghareeb *et al*., 2011). Several studies have shown lower disease severity in Si treated plants due to increased activity of defensive enzymes (Dann & Muir,

2002; Cai *et al*., 2008; Rodrigues,2005; Yang *et al.,* 2003). Si also acts as an elicitor of plant defenses by induction of defensive compounds in stressed plants (Chérif *et al*., 1994; Fawe *et al.,* 1998; Rodrigues *et al.,* 2004).

Si amendments may also aid in pest management indirectly by facilitating the activity of natural enemies and other mortality factors. Increase in Si content of plants may delay penetration by larval stem borers into the stem, thereby increasing time spent outside the stem and increasing exposure to natural enemies, adverse climatic conditions and insecticides (Kvedras & Keeping, 2007). Thus changes in stem borer behavior on Si amended plants may lead to greater reduction of stem borer population by natural mortality or by properly timed chemical control.

The greater responsiveness of the susceptible cultivar to Si amendment may provide rice growers with an option for cultivation of high yielding, borer susceptible cultivars in Louisiana when no other host plant resistance and chemical control options are viable or cost effective. Field studies by Bollich *et al.* (1996) demonstrated that the use of Si soil amendments in Louisiana had the potential to reduce disease incidence and increase grain yield. Soil Si amendments being easily applicable, may be applied on an areawide basis for management of the borer population, potentially reducing the need for insecticides. Si amendments are beneficial for plant and soil health besides having no adverse effects on environment. With the increasing need for environmentally safe strategies for insect pest management, Si could provide a valuable tool for use in agriculture. Future studies will focus on understanding the role of Si amendments as a component of IPM programs that incorporate insecticides, natural enemies and genotypes with varying levels of resistance against chewing pests.

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CHAPTER 5: EFFICACY OF DERMACOR- X-100® SEED TREATMENT AGAINST SUGARCANE BORER, *DIATRAEA SACCHARALIS,* IN RICE

Introduction

Stem borers have historically been considered important pests of rice in Louisiana and Texas (Douglas and Ingram 1942, Oliver et al 1972). Their incidence decreased in the 1980's probably as a result of the use of cultivars with greater resistance, improved cultural practices and extensive use of insecticides for stink bugs (Way 1990). The use of insecticides against stem borers was rarely justified during this period. In recent years, however, farmers have experienced an increase in stem borer infestations (Castro 2004, MO Way personal communication).

The stem borer complex attacking rice in the southern U.S includes the sugarcane borer (SCB), *Diatraea saccharalis* (F.), the stalk borer, *Chilo plejadellus* Zincken, and an invasive species; the Mexican rice borer, *Eoreuma loftini.* SCB is an economically important pest of graminaceous crops in Texas and Louisiana (Bowling 1967, Roe et al 1981, Williams et al 1969). The SCB has a wide host range with over 20 reported hosts (Holloway 1928). In the last few years, the sugarcane borer has steadily moved into central and north-eastern Louisiana. In 2002, this pest infested more than 1200 ha of rice in Concordia parish in Louisiana and caused 75- 95% loss of the crop on some farms (Castro 2004). Way et al (2006) reported that stem borer injury caused up to 60 % yield losses in untreated rice fields in Texas and, among all the stem borers recovered from their field samples, 60% were sugarcane borers. *Eoreuma loftini* was first discovered in the Lower Rio Grande valley of Texas in 1980 and has become the dominant insect pest of sugarcane since its detection in 1980 (Johnson 1984. By the end of 1980's its geographic range gradually expanded into the rice production area of Texas (Browning et al 1989) and caused large yield losses across the Texas rice belt (Reay-Jones et al. 2005). The Mexican rice borer has

invaded Louisiana from eastern Texas (Hummel et al. 2010) and has the potential to cause heavy economic losses (Reay-Jones et al. 2008) if it becomes established in areas where rice and sugarcane are grown.

Application of insecticides has always been a major tactic for managing stem borer infestations and yield losses in Texas (Browning et al 1989, Reay Jones et al 2007). Over the past few years stem borer control has been accomplished using pyrethroids applied as foliar sprays (Reay Jones et al 2007a). There are several issues with the use of pyrethroids. Negative aspects of the use of pesticides include pest resurgence, hazards to users, environmental contamination, need for multiple applications (Chelliah &Bharathi, 1994, Litsinger et al. 2005). Damaging stage of stem borers, the larva is an internal feeder and remains concealed inside the stem which reduces contact with chemicals (Litsinger et al 2005). There are no economic thresholds for stem borers in rice, making it difficult to determine when to treat and perhaps leading to overuse of insecticides. Research on the use of insecticides to manage stem borers in the USA has been sparse (Way 2003, Browning 1989). Because of the risk of resistance development and limited research, it is essential to investigate new chemistries as alternatives to existing conventional insecticides.

Chlorantraniliprole is a relatively new insecticide active ingredient. The seed treatment Dermacor X-100, which contains chlorantraniliprole as its active ingredient, is widely used as a seed treatment against rice water weevil, the most important early-season pest of rice in the U. S. Chlorantraniliprole is an anthranilic diamide that targets ryanodine receptors located on the sarcoplasmic reticulum of muscle cells leading to CA^{++} depletion, feeding cessation, lethargy, muscle paralysis and death in insects (Cordova et al 2006, 2007). Chlorantraniliprole is a systemic insecticide and generally persists in plants for long periods of time (Lahm et al. 2009). With the increasing impact of stem borers in rice, there is an urgent need to develop more sustainable and

effective management strategies. The objective of present study was to investigate the efficacy of different rates of Dermacor seed treatments on *D. saccharalis* in rice.

Material and Methods

Lab and greenhouse studies

Insects: *Diatraea saccharalis* larvae used in these experiments were obtained from a colony maintained continuously in the laboratory at Louisiana State University following the methods of Martinez et al (1988). The colony originated from larvae collected in rice fields near Crowley, LA, in 2005. Larvae were reared in 29.5 ml Solo soufflé cups (AceMart Restaurant Supply, San Antonio, TX) on sugarcane borer artificial diet (Southland Products, Lake Village, AR). Pupae were sexed following Butt and Cantu (1962) and equal numbers of males and females were placed into three liter plastic buckets with wax paper (Reynold's consumer products, Lake Forest, IL) as a substrate for oviposition. Adults were provided with a 1:1 mixture of honey and beer (Milwaukee's Best Light, Miller Brewing Co., Milwaukee, WI) and distilled water. Eggs were put into eight cell plastic trays (C-D International, Pitman, NJ) for hatching. When the eggs hatched, neonates were placed on the artificial diet in soufflé cups and reared until use. The colony was maintained under controlled environmental conditions (28°C ± 2°C; 30% R.H.). Insects collected from rice fields were added annually to the colony to maintain genetic variability.

Seed treatment: Seeds of the widely grown conventional rice cultivar 'Cocodrie' were used for treating with Dermacor-X-100®. Formulated insecticide was diluted in water containing a small quantity of brilliant blue dye and was applied using a pipette to seeds in Ziploc® bags to attain the desired treatment rate. Different treatment rates used in these studies are listed in Table 5.1. The

lowest rate on insecticide seed treatment used in this study (0.06 pound a.i per acre) corresponds to the lower limits of recommended field rates used in Louisiana against rice water weevil.

Plants: Plants for all experiments were grown in a greenhouse located on the campus of Louisiana State University, Baton Rouge. Insecticide treated and untreated 'Cocodrie' seeds were planted in a sterilized soil mix (2:1:1, soil: peat moss: sand) in 15cm diameter pots (3.8L) and plants were maintained in greenhouse conditions under ambient lighting at approximately 29°C- 33°C. At the time of planting, approximately 1.2g of 19:5:8 controlled release fertilizer (Osmocote, Scotts Miracle-Gro, Marysville, OH) was added to the soil. Plants were thinned to a density of one plant per pot five to seven days after planting.

Table 5.1 Insecticide rates and rice plant age used in lab and greenhouse experiments in different years

Year	**Location**	**Rate (mg ai/ seed)**	**Plant growth stage**
2010	Lab	0.03	40 days old
2011	Lab	0.03 0.06 0.09	45 and 60 days old
2012	Greenhouse	0.03 0.06 0.09	55 days old

Lab assays: The efficacy of Dermacor-X-100® on *D. saccharalis* larvae was investigated in laboratory experiments using cut stems and leaves in 2010 and 2011. In 2010 a single rate of Dermacor-X-100® was used for seed treatment (Table 5.1). When greenhouse-grown plants reached the mid-tillering stage (40 days after planting), they were brought back to the lab for setting up the experiment. For the stem assays, five stem pieces (each about 10 cm long) were cut

from the central tiller of 15 treated and 15 untreated plants. Cut stems from each plant were placed in the 14 cm petri dishes lined with wet filter paper. For the leaf assays, five leaf pieces approximately 10 cm long were cut from another 15 treated and 15 untreated plants and placed into large petri dishes separately. The experiment was conducted as a randomized block design with 15 replications. A block was a rack with petri dishes arranged randomly on it. In each block there were four petri dishes, one of each treatment* plant tissue combination. Five first instar larvae were released into each petri plate. The larvae had been taken off artificial diet and starved for three hours prior to release in the petri dishes with plant tissue. The petri plates were then sealed with parafilm (Beemis flexible packaging, Neenah, WI, USA) to prevent escape of the larvae. Observations for larval mortality were recorded after 72 h and percent mortality was calculated. Mortality was defined as lack of movement by larvae and no response to pricking by a camel hair brush.

In 2011, three different treatment rates of the insecticide were used along with the untreated controls (Table 5.1). The experiment was conducted at two stages of rice plant development- mid-tillering (45 d old) and late tillering (60 d old). Eight cell plastic trays (C-D International, Pitman, NJ) were used in this experiment in place of petri plates. The plastic trays were 40 cm long and 20 cm wide, divided into eight cells. When the greenhouse grown plants reached appropriate age, they were brought back to lab for experiment initiation. Stem and leaf pieces about 10 cm long were cut from the treated and untreated plants as described above. In the eight cell plastic trays, four cells contained leaf tissue and four cells contained stem tissues (one cell for each rate). The experiment was conducted as a RBD with seven replications for 45d old plants and eight replications for 60d old plants and each plastic tray was a block itself. Leaves and stems were infested by releasing ten first instars into each cell. The cells were sealed using plastic

covers (C-D International, Pitman, NJ). The eight cell trays were placed in the insect rearing colony room (28±2°C; 30% RH). Observations for larval mortality were recorded after 72 h and percent mortality was calculated. Mortality was defined as lack of movement by larvae and no response to pricking by a camel hair brush.

Data analysis: Data for lab assays in 2010 were analyzed as a factorial RBD experiment with block as a random effect and treatment and plant tissue as fixed effects using a mixed model analysis of variance in PROC MIXED (SAS Institute 1999). Means were separated using Tukey's HSD test (Tukey1953). Data from the 2011 were analyzed separately for 45 and 60 day old plants in a manner similar to the 2010 data.

Greenhouse studies: No-choice greenhouse studies using intact plants were conducted in 2012 to investigate the efficacy of Dermacor-X-100® against *D. saccharalis* larvae. The experiment was conducted twice in 2012. Three insecticide treatment rates were used along with the untreated control (Table 5.1). The experiment was conducted as a randomized block design (RBD) with five replications. Blocks consisted of groups of four plants, one plant from each treatment, spatially arranged on a greenhouse bench. When the plants reached the late tillering stage (50-55 days after planting), plants were infested using five first instar larvae per plant. Small plastic tubes were used as cages to confine insects on the plants. These tubes were 15 cm long and 2.5 cm in diameter. They were placed over the primary tiller of each plant and foam plugs were used to seal the top and bottom of the tube cages enclosing the stem. After 7 d, the plants were destructively sampled to calculate the number of dead larvae in each plant and percent mortality was calculated.

Data analysis: Data for the greenhouse study in 2012 was analyzed as a replicated RBD with block as a random effect and treatment as a fixed effect using a mixed model analysis of variance

in PROC MIXED (SAS Institute 1999). Means were separated using Tukey's HSD test (Tukey1953).

Field study: A field study was conducted in 2009 at the Louisiana State University Agricultural Center Macon Ridge Research Station, Winnsboro, LA, to assess the potential impact of a seed treatment Dermacor-X-100® on stem borer injury and to compare its efficacy with ten other insecticide treatments. Dermacor-X-100® is used to control the rice water weevil *Lissorhoptru oryzophilus* Kushel in Louisiana (Lanka et al 2012). The study was conducted as a randomized complete block design with four replications. Rice seeds of the borer-susceptible cultivar 'Cocodrie' (Way et al 2006) were drill-seeded at 100 kg/ha in plots measuring 8 rows (20 cm spacing) × 4.57 m plot on 24th June 2009. Permanent flood was established on 28th July. Standard agronomic practices for drill seeded rice in Louisiana were followed (Saichuk 2008). Insecticide treatments and rates are listed in Table 5.2. Applications of foliar insecticides were made when rice was at the 5 cm panicle elongation stage (Vergara, 2001) using a CO2 backpack sprayer with a pressure of 45 psi at 3 mph. At the time of application, heavy sugarcane borer infestations were observed in adjoining fields to the trial. Before harvest, four plants were randomly sampled from each plot to assess SCB injury to rice. Injury assessment was based on the total number of entry and exit holes observed in the stems of sampled plants.

Data analysis: Treatment effects on the total number of holes per plant were analyzed using a one way analysis of variance for a randomized block design in PROC MIXED (SAS institute 1999) with treatment as a fixed effect and replication as a random effect. Means were separated using Tukey's HSD test (Tukey1953).

Table 5.2 Insecticide rates and application methods used in field study in 2009

Insecticide		Application	Rate
Trade name	Common name		
Centric	Thiamethoxam	Foliar	0.03 lb AI/ acre
Belay	Clothianidin	Foliar	0.75 lb AI / acre
Control			
Coragen	Chlorantraniliprole	Foliar	0.04 lb AI / acre
Cruiser	Thiamethoxam	Seed treatment	0.03mg AI/seed
Cruiser+Karate	Thiamethoxam+Lambda-cyhalothrin	Seed treatment+ foliar	0.03mg AI/seed +0. lb AI / acre
Cruiser+Coragen	Thiamethoxam+ Chlorantraniliprole	Seed treatment+ foliar	0.03mg AI/seed +0. lb AI / acre
Dermacor	Chlorantraniliprole	Seed treatment	0.06 lb AI/ acre
Tenchu	Dinotefuron	Foliar	0.13 lb AI / acre
Endigo	Lambda-cyhalothrin+ Thiamethoxam	Foliar	0.03 lb AI / acre
Karate	Lambda-cyhalothrin	Foliar	0.04 lb AI / acre

Results

Lab studies: In 2010, feeding by *D. saccharalis* larvae on stems and leaves of Dermacor-treated plants resulted in significant mortality of larvae after a 72 h feeding period ($F_{1,56}$ =43.62 $P < 0.001$) (Figure 5.1). Larval mortalities were greater (50%) on plant tissues from Dermacor treated plants than on controls. Larval mortalities on stems and leaves did not differ significantly ($F_{1,56}$ =0.02 P =0.884), and the interaction between plant tissue and insecticide treatment was not significant ($F_{1,56}$ =0.19 P= 0.884).

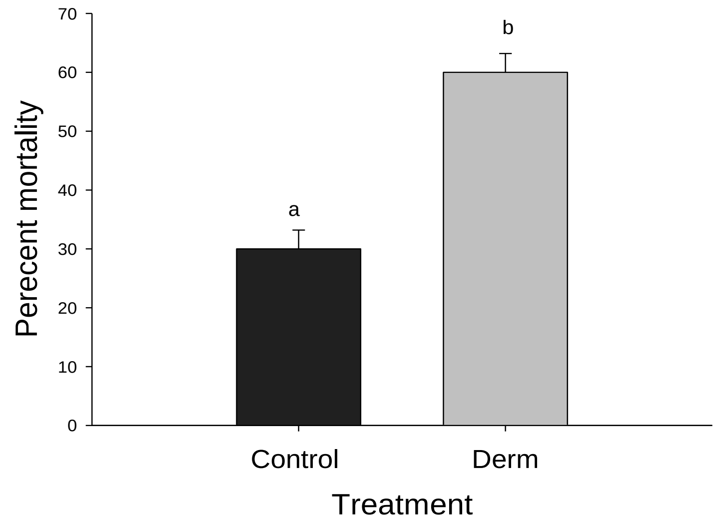

Figure 5.1 Mean (±SE) Sugarcane borer larval mortality on treated and control plant tissues in lab in 2010. Means accompanied by different letters indicate a significant difference (P <0.05).

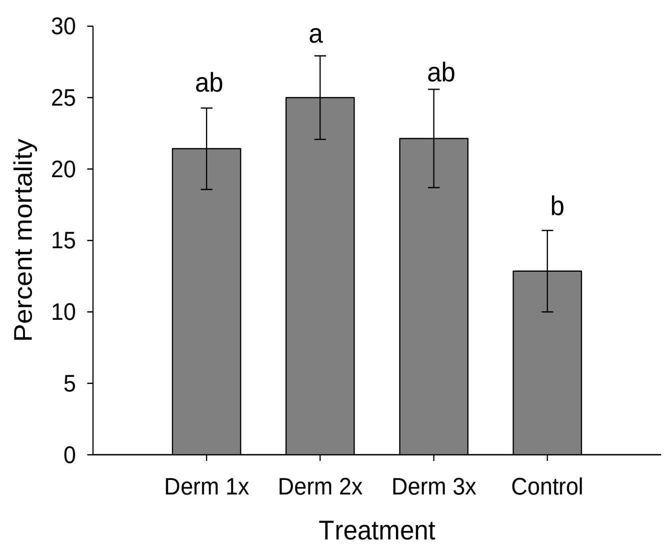

Figure 5.2 Mean (±SE) Sugarcane borer larval mortality on treated and control plant tissues of 45 days old plants in lab 2011. Means accompanied by different letters indicate a significant difference (P <0.05).

In 2011, on 45 day old plants, all seed treatment rates of Dermacor significantly increased larval mortalities compared to the control ($F_{3,48}$ =3.17 P = 0.033) (Figure 5.2). Mortalities did not differ on stems and leaves ($F_{1,48}$ =0.53 P =0.47), and the interaction between plant tissue and treatment was also not significant ($F_{3,48}$ =1.60 P = 0.203). Larval mortality was highest (25%) on plants grown from seeds treated with the 2X rate of Dermacor and was approximately double than control.

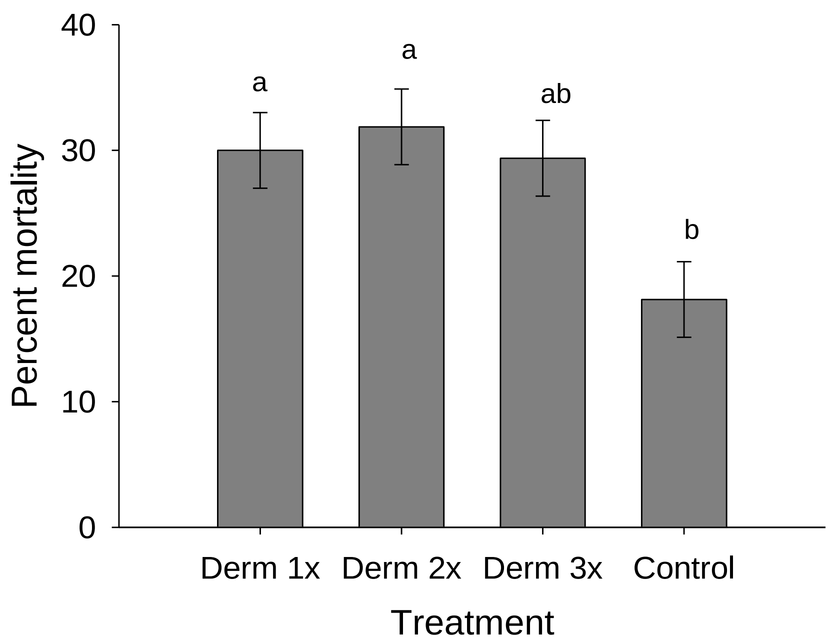

Figure 5.3 Mean (±SE) Sugarcane borer larval mortality on treated and control plant tissues of 60 days old plants in lab 2011. Means accompanied by different letters indicate a significant difference (P <0.05).

Similarly, on 60 day old plants, Dermacor seed treatments resulted in higher larval mortality compared to control ($F_{3,56}$ =4.31 P < 0.008) (Fig. 5.3). Larvae feeding on plants treated with 2X rate suffered highest mortality (31.87 %) followed closely by 1X rate (30.00 %) while there was only 18 % larval mortality on controls. There was no difference in larval mortality on

plant parts (stems and leaves) ($F_{1,56}$ =1.83 $P < 0.182$). Treatment*plant part was not significant for larval mortality.

Greenhouse studies: In 2012, Dermacor seed treatments were highly effective in the greenhouse no-choice studies using control and Dermacor-treated intact plants ($F_{3,27}$ =24.13 $P < 0.0001$) (Figure 5.4). Though there was no significant difference, larval mortalities resulting from feeding on treated plants increased with increasing seed treatment rates and ranged from 60- 80 % on the treated plants compared to 18 % on control.

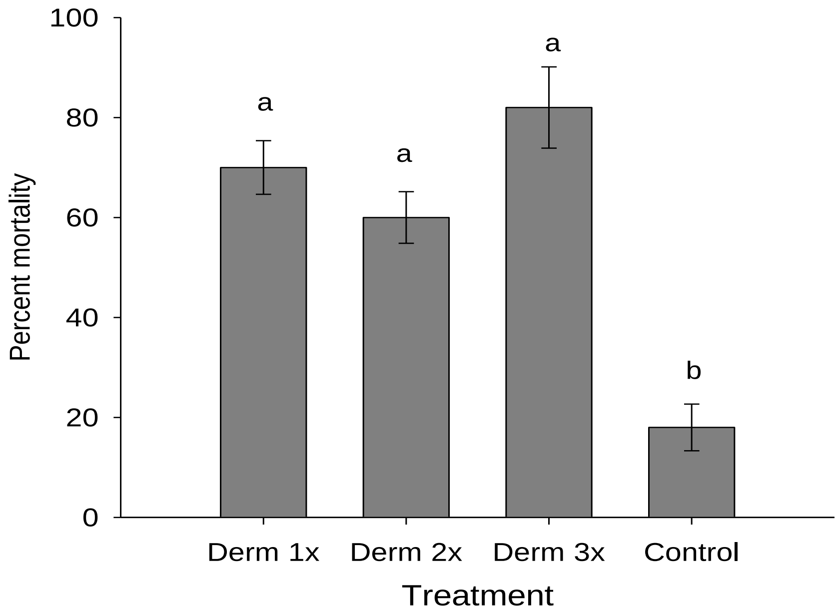

Figure 5.4 Mean (±SE) Sugarcane borer larval mortality on 60 days old intact plants in greenhouse 2012. Means accompanied by different letters indicate a significant difference ($P < 0.05$).

Field study: Numbers of entry/exit holes per plant differed among insecticide treatments ($F_{10,33}$ =4.12 $P < 0.001$) (Figure 5.5) and none of the insecticide treatments were as effective as the seed treatment Dermacor. The most effective insecticide was Dermacor with approximately 90% lower

number of holes compared to control and was significantly lower than other insecticide treatments. Numbers of holes per plant was highest on insecticide Centric and was comparable to untreated control.

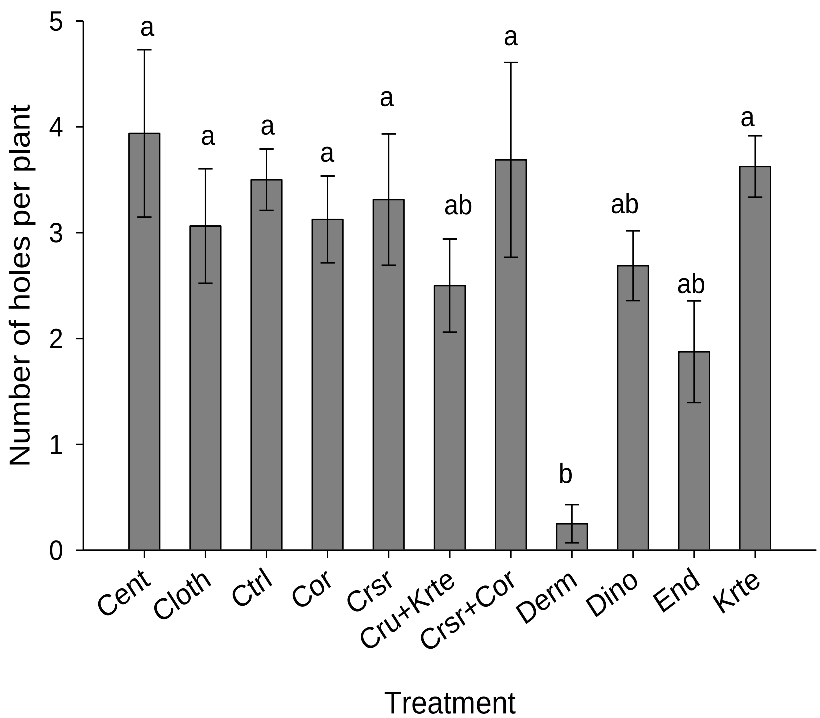

Figure 5.5 Mean (±SE) number of holes per plant on ten different insecticides used in field study in 2009. Means accompanied by different letters indicate a significant difference ($P < 0.05$).

Discussion

The stem borers *D. saccharalis* and *C. plejadellus* have historically been considered important insect pests in Louisiana rice (Douglas & Ingram 1942; Oliver *et al*., 1972), and serious infestations of these insects have been reported over the last decade in Louisiana (Castro *et al.*, 2004; MJS personal observartion). Moreover, another invasive stem borer species, *E. loftini*, has now moved through the Texas rice belt into Louisiana as predicted by Reay-Jones *et al.* (2008).

This species was first found in 2008 from two pheromone traps in Louisiana, approximately 8 km from a rice field near Texas border (Hummel *et al.*, 2010). Reay-Jones *et al*. (2008) predicted an annual loss of up to $45 million by MRB, assuming the entire rice industry is infested by this pest by 2035. Despite the importance of stem borers in the past and in the future, there is currently no sound management program for stem borers in Louisiana. This study was conducted to evaluate the efficacy of different rates dermacor against *D. saccharalis.* Results from the field study demonstrated that only Dermacor seed treatment resulted in significantly lower (94%) number of holes per plant compared to nine other insecticide treatments. In the greenhouse and lab studies on efficacy of Dermacor on *D. saccharalis* larvae, all rates of Dermacor caused significant mortality compared to control. In the lab assays using cut stems, Dermacor resulted in 40-50% more mortality than control while in the intact plant assays Dermacor resulted in 78 % more mortality. Results from these studies indicated that Dermacor seed treatment could be used as a valuable component of integrated pest management program for stem borer.

Insecticides are a primary tactic used to manage pests of rice with worldwide use estimated at $910 million in 1988 (Woodburn 1990) and $1.14 billion in 1996 (International Rice Research Institute World Rice Statistics). According to Chelliah and Bharathi (1994) chemical control is the only means of suppressing stem borers rapidly and economically. Limited research on the use of insecticides (Way 2003, Browning et al 1989), lack of economic thresholds and a history of resistance development by *D. saacharalis* to pyrethroid insecticides necessitates the need to evaluate new reduced risk chemistries which would manage the of stem borer populations with minimal effects on environment and health of farmers.

Two pyrethroid insecticides (lambda-cyhalothrin and zeta-cypermethrin) are currently labeled for stem borer control in U.S rice (Reay-Jones et al. 2007a). Insect growth regulators tebufenozide and novaluron reduce *D. saccharalis* and *E. loftini* injury in sugarcane (Reay-Jones et al. 2005b, Beuzelin et al. 2010a) but are less efficient than pyrethroids in rice (Castro et al. 2005, Reay-Jones et al. 2007a). Castro et al. (2005) reported that tebufenozide and methoxyfenozide significantly reduced whiteheads on rice due to *D. saccharalis* in Louisiana but whiteheads in these two treatments were 2.3-fold greater on average than plots with the pyrethroids. Reay-Jones et al. (2007) concluded that pyrethroids applied twice during the rice reproductive phase caused the greatest decrease in whiteheads and yield losses, and would increase farmer benefits. However, the effects of insecticide applications on yield losses were highly variable. Although studies have helped to better time insecticide applications, economic thresholds for stem borers in rice are lacking (Reay-Jones et al. 2007).

Way and Vawter (2001) evaluated selected insecticides for the control of stem borers in rice at Ganado, Texas. In their study, a combination of seed treatment with Icon 6.2FS followed by foliar application of Karate Z at panicle differentiation was the only treatment that significantly reduced the number of whiteheads. This combined treatment reduced whitehead counts by more than 50% and gave the greatest yield response of about 1512kg/ ha more than the untreated. Likewise, Way et al (2009) also evaluated Dermacor X-100 seed treatment for control of rice water weevil and stem borer complex. Although the whitehead densities were not high in untreated plots but Dermacor seed treatments provided considerable control of stem borers. In their study, highest rate of Dermacor (0.1 mg a.i per seed) provided complete control. In the present study, Dermacor seed treatment rates used were lower than the highest rate used in their study.

Stem borers are a bit difficult to control with chemicals even applied every 10 days over the growth of the crop with dosages at least twice as high as those used by farmers (Litsinger et al. 2006). The low control is understandable, however, based on the fact that larvae enter tillers within a few hours after hatching and only systemic materials could act on them once inside the plants. There is a very narrow time frame for application of foliar application to control the stem borers. Once inside the stem, the larvae are protected from coming into contact with the foliar insecticides. Foliar sprays targeted on eggs and larvae also come in contact with natural enemies of stem borers. Although cases of stem borer resurgence are not evident but secondary outbreaks have been reported in areas with heavy insecticide usage (Pathak and Khan 1994). Use of systemic insecticides can greatly improve the rice stem borer control and Dermacor is one such chemistry. Dermacor has a systemic mode of action and will kill the larvae when the larvae feed inside the rice stem. Pathak (1971) and Aquino and Pathak 1976 reported that granular formulations acting as systemic insecticides were more effective than conventional foliar insecticides for stem borer control. Use of systemic insecticides reduced the cost and number of insecticide applications needed for management of borer population (Pathak 1971). Granular insecticides, due to their systemic mode of action, absorbed by the roots of rice plant and will kill the stem borers. Bhutto and Soomro (2009) tested the efficacy of different granular insecticideas against yellow stem borer; *Scirpophaga incertullas* (Walker) and found that all these granular insecticides lead to a significant reduction in dead heart percentage, whitehead percentage and yield increase compared to the control.

With the increasing impact of stem borers on rice in the southeastern United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics. A greater sustainability in IPM program is often achieved by balanced use of different

control tactics (Luckman and Metcalf 1994). Dermacor seed treatment along with resistant cultivars and cultural control may contribute to management of the borer population on areawide basis. It has the potential to reduce the cost and number of insecticide applications in rice. A previous study (Srinivas et al 2012) has reported a systemic activity of Dermacor against first instar larvae of rice water weevil feeding on rice shoots. Having efficacy against stem borers and rice water weevil, it has the potential to protect rice from multiple pests. This insecticide may be economical to use since it has activity against multiple pests. Future research should focus on studying the integration of Dermacor seed treatments with cultivar resistance and cultural control especially soil silicon amendment.

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CHAPTER 6: COMPENSATORY RESPONSES OF RICE TO SUGARCANE BORER (*DIATRAEA SACCHARALIS*) INJURY

Introduction

Stem boring insects in rice, nearly all of them Lepidopterans in the families- Crambidae and Noctuidae, are found in all important rice producing regions of the world (Chaudhary et al., 1984). Borers attack rice plants from seedling to maturity and are one of the reasons for low yields in the rice growing countries of Africa and Asia (Akinsola, 1984). The life cycles and damage caused by these boring Lepidopterans are similar. The damaging stages of stem borers, the larvae, are internal feeders. Eggs are laid in masses of usually 2- 100 eggs with individual eggs overlapping and forming a fish scale like appearance. First and second instars feed on leaf blades or in between the leaf sheath and the stem. Initial feeding by the larvae in the leaf sheath causes broad longitudinal reddish brown lesions at the feeding sites. Shortly thereafter, larvae bore into the stem and feed internally. Larvae pass through four to five instars and a pupal stage in in the stem in four to five weeks. At the vegetative stage of rice plant growth, feeding by stem borer larvae results in "deadhearts", in which the young tillers and the leaves of the tillers die. During the reproductive stage, injury to tillers can destroy the panicles resulting in "whiteheads". Extensive feeding can also lead to lodging of rice plants (Pathak, 1968; Holloway, 1928; Castro *et al.*, 2004).

Stem borer species that have been reported to infest rice in the southern United States include the rice stalk borer; *Chilo plejadellus* Zincken, and the sugarcane borer, *Diatraea saccharalis* (F.). The sugarcane borer is a major agronomic pest in the southeastern U.S. Holloway *et al.* (1928) reported more than twenty host plants for the sugarcane borer. In addition to sugarcane (*Saccharum officinarum* L.), it is an economically important pest of corn (*Zea mays* L.), rice, and sweet sorghum (*Sorghum bicolor* L. Moench) (Roe *et al.*, 1981). In recent years, rice farmers in the

southern U.S have experienced increased problems with *D. saccharalis*. In 2002, for example, approximately 1200 acres of rice in Concordia parish in central Louisiana were infested with *D. saccharalis*, damaging 70 to 95 percent of the rice crop on some farms (Castro *et al.*, 2004). Moreover, another stem-boring species, the Mexican rice borer, has invaded Louisiana (Hummel *et al*., 2010) and has the potential for inflicting significant economic losses (Reay-Jones *et al*., 2008).

Compensation refers to plant physiological responses to insect injury that serve to partially or completely mitigate or ameliorate yield losses (Bardner and Fletcher 1974, Pedigo 1991). Many studies have shown compensation to insect injury (Trumble et al 1993). Rice plants have been shown to compensate for stem borer injury to some extent by producing greater numbers of reproductive tillers, producing heavier panicles on healthy tillers, and, in some cases, by redirecting nutrients from injured tillers to healthy ones (Akinsola 1984, Rubia et al 1990, 1996, Soejinto 1979, Gill 1992, Islam and Karim 1997,1999, Jiang and Cheng 2003). In general, compensation is greater when injury takes place at early plant growth stages than at late stages. Islam and Karim (1997) studied the association of whiteheads with stem borer infestation in modern varieties and reported that compensation for stem borer infestation at the reproductive stage was due to conversion of some unproductive tillers to productive tillers, by producing more and heavier grains on healthy tillers of injured plants and by producing tillers from aerial nodes. In their study rice plants compensated for about 23% of the yield losses due to whiteheads and the amount of compensation was strongly influenced by physical factors (Islam and Karim, 1997). El-Abdallah and Metwally (1984) observed a heavier 1000 grain weight when there were 10% deadhearts and at 2% and 6% whiteheads relative to uninfested plants.

In previous studies, oviposition preference and larval performance of sugarcane borers was found to differ among eight cultivars of rice widely grown in Louisiana (Hamm et al 2011, Sidhu et al 2013 unpublished). In these studies, there was a significant positive correlation between oviposition preference and larval performance. Some of the cultivars were less preferred for oviposition compared to others and the larval performance was also lower on those cultivars. The objective of the present study was to 1. Investigate whether these same eight cultivars also show compensatory responses to stem borer injury and to quantify these responses and 2. Determine whether the eight cultivars differ in their ability to sugarcane borer injury.

Materials and Methods

Insects: Larval *D. saccharalis* used in experiments were obtained from a colony maintained in the laboratory at Louisiana State University following the methods of Martinez et al (1988). The colony originated from larvae collected in rice fields near Crowley, LA, in 2005. Larvae were reared in 29.5 ml Solo soufflé cups (AceMart Restaurant Supply, San Antonio, TX) on sugarcane borer artificial diet (Southland Products, Lake Village, AR). Pupae were sexed according to Butt and Cantu (1962) and equal numbers of males and females were placed into three liter plastic buckets with wax paper as a substrate for oviposition. Adults were provided with a 1:1 mixture of honey and beer (Milwaukee's Best Light, Miller Brewing Co., Milwaukee, WI) and distilled water. Eggs were put into eight cell trays for hatching. When the eggs hatched, neonates were placed on artificial diet and reared until use. The colony was maintained under controlled environmental conditions (14L;10D, 28°C ± 2°C, 38% R.H. ± 2% R.H.). Insects collected from rice fields were added annually to the colony to maintain genetic variability.

Compensation studies: An experiment using greenhouse-grown plants was conducted once in 2009 and twice in 2010 to assess the compensatory response of different rice cultivars to *D. saccharalis* injury at an early plant growth stage (early tillering). The greenhouse was located on the campus of Louisiana State University, Baton Rouge. Eight rice cultivars (Table 6.1) were used that collectively represented approximately 75% of the rice acreage in Louisiana from 2010-2011 (LSU Agcenter 2010, 2011) The cultivar Priscilla, which is not widely grown in Louisiana, was included in experiments as a susceptible standard (Way et al. 2006). Seeds were planted in a sterilized soil mix (2:1:1, soil: peat moss: sand) in 15cm diameter pots (3.8L) and plants were maintained under ambient lighting at approximately 29°C-33°C. At the time of planting, approximately 1.2g of 19:5:8 controlled release fertilizer (Osmocote, Scotts Miracle-Gro, Marysville, OH) was added to the soil. Plants were thinned to a density of one plant per pot five to seven days after planting. The designation of rice plant stages followed the system outlined by Counce et al (2000). The experiments were conducted as a randomized block design with five replications. Blocks consisted of groups of sixteen plants (one infested and one control plant of each cultivar) spatially arranged on greenhouse benches. At the early tillering stage (35-40 days old), designated plants were infested using one second instar larvae per plant. Small plastic tube cages (Icon Plastics, Costa Mesa, CA) were used to confine insects on the plants. These tubes were 15 cm long and 2.5 cm in diameter. Tubes were placed over the primary tiller of each plant and foam plugs were used to seal the top and bottom of the tube cages enclosing the stem. Six weeks after infestation, numbers of healthy tillers on each infested and control plant were counted. The infested tillers (if healthy) were also counted. The primary infested tiller died in most of the plants and in some plants neighboring tillers were also affected. After harvesting, the numbers of panicle and then seeds on all panicles were counted on both infested and control plants.

Table 6.1 Rice cultivars used for compensation studies greenhouse studies in 2009 and 2010

Cultivar	Rice Type	**Greenhouse Study**	
		2009	2010
Cocodrie	Long grain	X	
Cheniere	Long grain	X	X
Priscilla	Susceptible check	X	X
Bengal	Medium grain	X	X
Jupiter	Medium grain	X	
Jazzman	Aromatic long grain		X
CL151	Long grain Clearfield		X
CL161	Long grain Clearfield	X	X
XL723	Long grain Hybrid	X	X
XP744	Long grain Hybrid	X	

Using the numbers of panicle and seeds per panicle, total seeds per plant were estimated. In 2010, there were only seven cultivars as Cocodrie was taken out due to large variations and one replication was taken out due to abnormal behavior in control plants.

Data analysis: Data from 2009 were analyzed as a RBD using a mixed-model ANOVA in PROC MIXED (SAS institute 1999) with block as a random effect and cultivar, treatment and cultivar*treatment as fixed effects. Data for the two plantings in 2010 were pooled and analyzed as a replicated RBD using a mixed-model ANOVA in PROC MIXED (SAS institute 1999) with planting and block (planting) as random effects and cultivar, treatment and cultivar*treatment as fixed effects. Means were separated using Tukey's HSD test (Tukey 1953).

Results

Number of tillers: 2009: There was a significant effect of larval injury on the average number tillers per plant ($F_{1, 60}$=8.06 P=0.006) (Table 6.1). Plants with larval injury produced 17 % more tillers compared to control plants. Cultivar also had a significant effect on numbers of tillers per plant ($F_{7, 60}$=12.64 P<0.001) with greatest numbers of tillers per plant found in the hybrid XP744 closely followed by another hybrid XL723. Numbers of tillers per plant on Cheniere was significantly different from the hybrids while numbers of tillers on other cultivars were intermediate and did not differ significantly. The effect of larval injury*cultivar interaction on numbers of tillers per plant was non-significant ($F_{7, 60}$=1.86 P=0.09). CL161 exhibited the greatest difference in number of tillers in infested and control plants followed by the medium grain Bengal and Jupiter while there was no increase in number of tillers in Cheniere and Cocodrie infested and control plants.

2010: There was a significant effect of larval injury on the average number tillers per plant ($F_{1, 125}$=10.96 P=0.001). Plants with larval injury produced 18.2 % more tillers compared to control plants. Cultivar also had a significant effect on number of tillers per plant ($F_{7, 125}$=8.51 P<0.001) (Table. 6.2). The greatest number of tillers per plant was found in Hybrid XL723 (6.2±0.43 tillers per plant). The number of tillers per plant was lowest in Cheniere (3.4±0.34 tillers per plant) and was significantly lower than in XL723, Jazzman, CL161 and Bengal. Number of tillers per plant on other cultivars was intermediate. The larval injury*cultivar interaction effect on number of tillers per plant was not significant ($F_{7, 125}$=0.61 P=0.72).

Number of seeds per plant: 2009: The data for number of seeds per plant revealed a significant effect of larval injury ($F_{1,64}$=6.10 P=0.02) on number of seeds per plant and there were 44 % more

Table 6.2 Average number of tillers per plant (± SE) in sugarcane borer infested and control plants in each cultivar in 2009. Means within a column followed by the same lower case letter do not differ significantly (p<0.05)

Variety	Number of tillers		
	Control	Infested	% increase in tillers
Bengal	4.0 ± 0.45	5.6 ± 0.51	40%
CL161	2.0 ± 0.83	4.2 ± 0.20	110%
Cheniere	2.6 ± 0.51	1.6 ± 0.68	-38%
Cocodrie	3.4 ± 0.51	3.4 ± 0.51	0%
Priscilla	3.0 ± 0.45	3.2 ± 0.20	7%
XL723	5.0 ± 0.71	5.6 ± 0.40	12%
Jupiter	3.6 ± 0.40	4.6 ± 0.68	28%
XP744	5.4 ± 0.51	6.8 ± 0.73	26%

Table 6.3 Average number of tillers per plant (± SE) in sugarcane borer infested and control plants in each cultivar in 2010. Means within a column followed by the same lower case letter do not differ significantly (p<0.05).

Variety	Number of tillers		
	Control	Infested	% increase in tillers
Bengal	5.3 ± 0.65	5.5 ± 0.40	4%
CL151	4.0 ± 0.39	4.6 ± 0.64	15%
CL161	4.7 ± 0.47	6.2 ± 0.77	32%
Cheniere	4.0 ± 0.31	5.0 ± 0.62	25%
Priscilla	4.3 ± 0.54	5.2 ± 0.55	21%
XL723	5.4 ± 0.27	7.0 ± 0.76	30%
Jazzman	5.7 ± 0.93	5.7 ± 0.93	0%

seeds per plant in control plants compared to infested plants (Table 6.3). There was a significant effect of cultivar on number of seeds per plant ($F_{7, 64}$=13.77 P<0.0001). Number of seeds per plant was highest in XL723 (816.20±57.78 seeds per plant) followed closely by XP744 (564.90±57.78 seeds per plant). The number of seeds per plant was lowest in Cheniere (207.90±57.78 seeds per plant) and was significantly different from XL723. The larval injury*cultivar interaction on number of seeds per plant was not significant ($F_{7, 64}$=0.62 P=0.74). For number of seeds per plant, only CL161 showed compensation by increasing number of seeds in infested plants while there was no compensation in other cultivars. There was no significant effect of larval injury on 100 seed weight (Data not shown).

Table 6.4 Average number of seeds per plant (±SE) in sugarcane borer infested and control plants in each cultivar in 2009 Means within a column followed by the same lower case letter do not differ significantly (p<0.05).

Variety	**Number of seeds per plant**		
	Control	**Infested**	**% increase/decrease**
Bengal	342.80 ± 80.31bcd	179.60 ± 42.46d	- 47%
CL161	249.00 ± 106.85d	330.40 ± 64.41 cd	32%
Cheniere	235.00 ± 40.99d	180.80 ± 82.39d	- 23%
Cocodrie	378.00 ± 67.73bcd	312.00 ± 123.18cd	- 17%
Priscilla	298.20 ± 18.62cd	185.40 ± 51.59d	- 38%
XL723	883.40 ± 131.58a	749.60 ± 101.03ab	- 15%
Jupiter	284.80 ± 43.36cd	150.60 ± 22.36d	- 47%
XP744	676.60 ± 125.80abc	453.20 ± 77.88bcd	- 33%

2010: There was no significant effect of larval injury on number of seeds per plant ($F_{1, 98}$=0.34 P=0.56) although there were 4.3 % more seeds per panicle in infested plants than control plants. There was a significant effect of cultivar on number of seeds per plant ($F_{6, 98}$=6.57 P=0.001) (Table. 6.4). Number of seeds per plant was highest in XL723 (705.06±44.89 seeds per plant) followed by Bengal. Number of seeds per plant was lowest in Jazzman (389.44±44.89 seeds per plant) and was significantly different from XL723. Effect of larval injury*cultivar interaction on number of seeds per plant was not significant ($F_{7, 144}$=0.81 P=0.58).

Table 6.5 Average number of seeds per plant (±SE) in sugarcane borer infested and control plants in each cultivar in 2010. Means within a column followed by the same lower case letter do not differ significantly (p<0.05)

Variety	**Number of seeds per plant**		
	Control	**Infested**	**% increase/decrease**
Bengal	546.20 ± 32.48bc	543.89 ± 53.79c	- .4 %
CL151	361.38 ± 39.44 c	440.13 ± 43.11bc	22 %
CL161	417.63 ± 44.05abc	454.13 ± 72.34abc	8.7 %
Cheniere	427.38 ± 65.08bc	411.75 ± 41.64bc	- 3.7 %
Priscilla	427.75 ± 42.22c	393.13 ± 31.50c	- 8 %
XL723	691.12 ± 69.43a	719.00 ±149.15ab	4 %
Jazzman	365.50 ± 41.81c	413.38 ± 62.27abc	13 %

Discussion

Stem borers are among the most important pests of rice globally and are becoming increasingly important pests of rice in the southeastern United States. This study was conducted to assess the compensatory response of the eight rice cultivars to sugarcane borer injury in Louisiana

rice. The cultivars used in these experiments collectively represented approximately 75% of the rice acreage in Louisiana in 2010-2011. These cultivars were used previously in oviposition preference and larval performance studies of sugarcane borer. Both cultivar and larval infestation affected the compensation ability of rice plants. Number of tillers was higher in infested plants as compared to uninfested control plants. CL161 and the hybrids XP744 and XL723 produced more tillers as compared to the conventional cultivar Cocodrie and Cheniere. XL723 and CL161 showed compensation by having more number of seeds per plant in infested plants. These results suggest that plant compensation mechanism to SCB injury could be used as a strategy for borer management in integrated pest management programs.

Rice plants can compensate for stem borer injury by production of new tillers, increasing number of and weight of grains (Rubia et al 1996, Islam and Karin 1997). Rice plants can compensate by translocating assimilates from injured to healthy tillers however translocation is more active at vegetative stage than at the reproductive stage (Rubia et al 1996). Akinsola (1984) reported that infestations by *Sesamia botanephaga* Tams and Bowden at the tillering and boot stage of rice plants resulted in a significantly higher number of tillers. However at harvest uninfested plants had higher number of productive tillers indicating that the initial increase in number of tillers in infested plant did not result in a corresponding increase in number of productive tillers. Ishikura (1967) concluded that there were more grains per panicle in the healthy tillers of infested plants than the uninfested plants. An increase in the grains weight of seeds on healthy tillers of infested plants indicated that the plants compensated for the loss caused due to stem borer injury by better ripening of the fertilized spikelets on uninfested tillers.

Lv et al (2008) reported that rice plants can compensate for upto 10%, 17 % and 14 % of stem injury when infested by sugarcane borers at tiller, panicle differentiation and heading stage respectively. Lv et al (2008) also reported that compensation by production of additional tillers occurred only in the injured pants not on the neighboring plants. They also reported differential sensitivity of rice to the type of larval injury and the stage of crop growth when injury occurs. Rice plants compensate by production of larges panicles when injury is restricted to leaf sheath. If the larvae bore through rice culms, injury will either kill the panicles or result in partial yield reduction. The greatest compensation was observed at the panicle differentiation stage.

Compensation by plants varies with the growth stage of the plants. Islam and Karim (1999) reported that plants can compensate for up to 20% of deadhearts when injury occurs at vegetative stage, although new tillers produce lighter panicles. When injury occurs at reproductive stage, rice plants compensate for stem borer injury by converting unproductive tillers to productive tillers and by production of tillers from aerial nodes (Islam and Karim 1997).

Pathak and Patnakamjorn (1971) reported that the tolerance and compensation ability of rice plants at different crop stages may differ among cultivars. Ishikura (1967) reported that the recovery of rice plants from injury by first generation *Chilo suppresalis* Walker injury was often high and varies with the tillering ability of varieties, soil type and weather in the single crop system in Japan. Modern varieties have a great tolerance to insect defoliation and can also tolerate substantial tiller loss (Litsinger 2009). Rice varieties have been bred to be high tillering (Khush 2001) as high tillering have been associated with the greater ability of crop to compensate for missing tillers that may be caused by pest damage or poor stand of crop (Litsinger 1991). Rubia and Penning de Vries (1990) reported that reallocation of photosynthates from damaged to

undamaged tillers leads to compensation due to whiteheads caused by stem borers. Rubia et al (1990) reported that upto 30% dead hearts and less than 20 % whiteheads do not lead to substantial yield losses.

Tillering by rice plants is strongly influenced by nitrogen supply; compensation may be increased by fertilization application. Ishikura et al (1953) observed an increase in compensation ability of rice plants following an increase in application of nitrogenous application. In India, topdressing with ammonium sulphate to help to enhance recovery of rice plants damaged by stem borers has been professed (McNaoghton 1946). Areas where rice crops are grown under high levels of nitrogen, cultivars which are more tolerant to stem borer injury should be chosen (Rubia et al 1996)

With the increasing impact of stem borers on rice in the southeastern United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics. A greater sustainability in IPM program is often achieved by balanced use of different control tactics (Luckman and Metcalf 1994). One possible approach to use in pest management program is to recommend those cultivars that have enhanced mechanisms of compensation to stem borer injury. The use of moderately resistant cultivars which can compensate against stem borer injury could be used in breeding programs for resistance against stem borers.

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CHAPTER 7: SUMMARY AND CONCLUSIONS

The sugarcane borer, *Diatraea saccharalis* (F.), is a major agronomic pest in the southern United States. It has a wide host range with more than twenty reported host plants. In addition to sugarcane (*Saccharum spp.*), it is an economically important pest of corn, rice and sweet sorghum. In recent years, rice farmers in the southern United States have experienced increased problems with *D. saccharalis*. In addition to *D. saccharalis*, another stem borer, *Chilo plejadellus* Zincken, is also an occasional pest in rice. Moreover, a third stem-boring species, the Mexican rice borer, *Eoreuma loftini* (Dyar), has reached Louisiana and has the potential to cause significant economic losses. With the increasing impact of stem borers on rice in the United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics; host plant resistance, chemical control and cultural control.

In a previous study (Hamm, Sidhu et al. 2012), oviposition preference of sugarcane borers was found to differ on eight cultivars of rice widely grown in Louisiana. Follow up studies were conducted to characterize variation in resistance among those eight cultivars and to investigate the relationship between larval performance and oviposition preference. Three different measures of larval performance - boring success, relative growth rate of larvae, and time until entry into the stems were used to characterize Variation in resistance among these eight cultivars was moderately strong. In the larval performance experiments, reductions in boring success and relative growth rate of larvae on resistant cultivars ranged from 30-50 % relative to the susceptible cultivars. Similarly, oviposition preference was 50-60 % lower on resistant cultivars and the females distinctly preferred to lay more eggs on Priscilla and Cocodrie compared to the hybrid XL723 and the Clearfield cultivars. In addition, resistance was fairly consistent across experiments. Priscilla and Cocodrie were always among the most susceptible cultivars, while the hybrid XL723, the

medium grain Bengal and the herbicide tolerant long grain CL161 were always among the resistant cultivars. There was a good correspondence among measures of larval performance and oviposition preference. Significant positive correlations were observed among boring success, relative growth rate and oviposition preference. Results from the field experiment corresponded well with lab and greenhouse studies, with Cocodrie and Cheniere being the most injured cultivars while CL161 and the medium grain Jupiter were least injured in terms of average number of stem borer entry/exit holes per plant. These results suggest that cultivar resistance has the potential to contribute to the management program for stem borers at present.

The potential of Si soil amendments (as a cultural practice) to increase rice resistance to *D. saccharalis* was investigated. Two cultivars, 'Cocodrie' and 'XL723,' were used. Prior experiments have shown Cocodrie to be susceptible to *D. saccharalis* while XL723 has been found to be moderately resistant. At the two leaf growth stage of rice plants, plants assigned to the Si augmentation treatment were treated by adding calcium silicate (slag)) at 4 m^3 tons ha^{-1} (7.3g per pot) directly on the soil surface in the pots. This rate was chosen because it represents the highest field rate that could be potentially used economically in the field and would potentially have the maximum Si response (Datnoff, 1997). Incorporation of Si into the soil led to an uptake of Si and an increase in Si tissue concentrations in both rice cultivars. Soil Si augmentation increased the Si content in the plant tissues by approximately 32 and 17% in Cocodrie and XL723, respectively. A positive effect of Si augmentation on rice resistance was observed in both greenhouse and lab studies. Soil Si amendment led to a significant reduction in both RGR's and boring success of larvae on Si treated plants. Although the increases in plant Si content did not significantly differ among the two cultivars, a stronger increase in resistance was observed in the more susceptible

cultivar, Cocodrie, compared to the moderately resistant XL723. Thus, this study was a robust demonstration of the potential for Si to increase resistance to stem borers in U.S rice.

The seed treatment Dermacor X-100, which contains chlorantraniliprole as its active ingredient, has been registered over the past several years for use in rice in the southern United States against the rice water weevil, the major early season insect pest of rice in the U.S. The efficacy of different rates Dermacor against *D. saccharalis* was evaluated. In the field, Dermacor seed treatment resulted in lower numbers of holes per plant compared to nine other insecticide treatments. In greenhouse and lab studies on efficacy of Dermacor on *D. saccharalis* larvae, all rates of Dermacor caused significant mortality compared to control. In lab assays using cut stems, Dermacor resulted in 40-50% greater mortality than control while in the intact plant assays Dermacor resulted in 78 % more mortality. Results from these studies indicated that Dermacor seed treatment could be used as a valuable component of integrated pest management program for stem borer.

Rice plants can compensate for stem borer injury by production of new tillers, increasing number of and weight of grains (Rubia et al 1996, Islam and Karin 1997). This study was conducted to assess the compensatory response of rice to sugarcane borer injury in Louisiana. Both cultivar and larval infestation affected the compensation ability of rice plants. Number of tillers was higher in infested plants as compared to uninfested control plants. CL161 and the hybrids XP744 and XL723 produced more tillers as compared to the conventional cultivar Cocodrie and Cheniere. XL723 and CL161 showed compensation by having more number of seeds per plant in infested plants.

VITA

Jaspreet Kaur Sidhu was born and raised in Barnala, a town in the state of Punjab, India. She finished her high school education in the same town. After that, she enrolled at the Punjab Agricultural University, Ludhiana, Punjab, India where she received her undergraduate degree in agricultural science with a major in plant protection. She then continued her education for Master's degree in Entomology from the same University and graduated with a Master's degree in 2007. She aspired to continue her higher education from U.S. and decided to pursue a doctorate degree from the United States. She left India and moved to the United States in January 2008 and enrolled into a doctorate program under the supervision of Dr. Michael Stout in the Department of Entomology at Louisiana State University and Agricultural and Mechanical College. She is currently completing the requirements for the Doctor of Philosophy and plans to pursue a career in research and teaching.