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Evaluation of Economic Injury Levels and Chemical Control Recommendations for Rice Stink Bug (Oebalus Pugnax) in Louisiana

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EVALUATION OF ECONOMIC INJURY LEVELS AND CHEMICAL CONTROL RECOMMENDATIONS FOR RICE STINK BUG (*OEBALUS PUGNAX*) IN LOUISIANA

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ABSTRACT

Experiments were carried out from 2010 to 2013 to investigate multiple aspects of rice stink bug (RSB) integrated pest management (IPM): insecticide recommendations, sampling efficiency, treatment thresholds, farmer practices, and improved educational tools. The first objective of this research was to compare the efficacies of currently used insecticides with that of a new product from the neonicotinoid class of insecticides. Experiments were carried out in the laboratory, small field plots, and commercial fields across Louisiana. Results from efficacy trials showed that the neonicotinoid was comparable to pyrethroid products used most by rice producers in Louisiana. Conversely, in separate experiments the organophosphate malathion was shown to be highly ineffective in small plot tests. Glass-vial bioassays showed elevated levels of pyrethroid tolerance in a Texas RSB population. The second objective was to evaluate the density-damage relationship for rice stink bugs feeding in rice. The efficiency of sweep-net sampling was first determined using a mark-recapture study in small plots to establish the necessary density for infesting caged rice plots. Cage studies were carried out in 2010-2012, and RSB were infested at levels estimated to be 1 to 20 times the current economic thresholds. No significant relationships among rice stink bug densities and measures of damage were seen. Objective three was to assess the adoption of recommended IPM practices by rice-industry professionals in southern rice producing states and create original internet-based delivery of extension recommendations for RSB management. Rice producers in Louisiana and Texas were shown to prefer the use of pyrethroid insecticides above all other labeled products for RSB control. Growers in Texas averaged more applications of pyrethroids than respondents in Arkansas and Louisiana. Seed treatments to combat rice water weevils have been adopted rapidly in all states surveyed.

CHAPTER 1: GENERAL INTRODUCTION

Rice Cultivation

Rice was harvested on 161 million ha globally and 1 million ha in the United States in 2013. The U.S. exported 5.1 million metric tons of rice in 2013, placing it third among global exporters behind Thailand and Vietnam (USDA-ERS 2014). Approximately 17% (167,000 ha) of the rice crop produced in the U.S. in 2013 was grown in Louisiana, and Louisiana consistently produces the third largest rice crop in the U.S. annually behind Arkansas and California. Rice is also produced in (in order of acres harvested): Texas, Missouri, Mississippi, and Florida. The majority of rice acres in the Southern U.S. are drill-seeded, long-grain cultivars grown under irrigation (USDA ERS 2014).

Modern rice production methods in the U.S. were directly impacted by the efforts of Henry Beachell, Norman Borlaug, the Green Revolution, and the creation of the International Rice Research Institute (IRRI). In 1966, rice breeders at IRRI released the first semi-dwarf high yielding variety (HYV) of rice, IR8, to the public. The release of IR8 was followed by other similar varieties that were distinguished by their decreased stalk height, increased leaf area, and increased harvest index. These changes resulted in dramatic yield increases that have continued with the innovation of hybrid rice in Asia and the Americas.

Both abiotic and biotic factors contribute to reduced rice yield production. Weather conditions such as cloud cover and high nighttime temperatures cause significant reductions in photosynthesis and increased respiration. Weather conditions may also contribute to increased disease and insect prevalence in Louisiana rice fields (Douglas and Ingram 1942, Rashid et al. 2005). Louisiana consistently produces the lowest yields per area planted of the six leading rice-producing states in the U.S. (USDA 2014). Two arthropod pests, the rice water weevil, *Lissorhoptrus oryzophilus* (Coleoptera: Curculionidae) and the rice stink bug (RSB), *Oebalus pugnax* F. (Hemiptera: Pentatomidae), are considered the primary early and late season pests of rice in Louisiana, respectively (Way 1990).

Rice Stink Bug

The rice stink bug is the pest of primary importance in headed rice due to the damage the insect causes when feeding on developing rice grains (Riley 1882; Webb, 1920; Douglas, 1939; Douglas and Ingram, 1942; Sailer, 1944; Brook, 1953; Swanson and Newsom, 1962; Odglen and Warren, 1962; McPherson, 1982; Way, 1990). Rice stink bugs cause damage to rice by feeding during the flowering, grain filling, milk, and dough stages of grain development. Feeding results in grains that are empty or partially-filled and kernels that are discolored and broken. Yield loss and USDA grade reductions due to discoloration and broken kernels result in lost income for producers. Feeding in the milk and soft dough stages of development reportedly lead to higher incidence of pecky rice (Espino 2008). Multiple attempts have been made to determine effective economic thresholds (ET) for RSB adults and nymphs, and results have varied considerably with each experiment (Douglas and Tullis 1950, Odglen and Warren 1962, Swanson and Newsom 1962, Bowling 1963, Robinson et al. 1980, Harper et al. 1993, Tindall et al. 2004, Patel et al. 2006, Espino 2007). Reduced tolerance for pecky rice in major export markets has increased the interest in establishing a more sensitive ET for RSB.

Louisiana treatment thresholds for management of RSB populations have been in place since the early 1980's. Current LSU Agricultural Center recommendations suggest sweeping 10 times in 10 locations throughout a field with a 38 cm sweep net. Control options for RSB populations at treatment threshold prior to 2010 consisted of pyrethroids, organophosphates, and carbamates. The EPA rescinded the label for one organophosphate, methyl parathion, and the other, malathion, has been used for RSB for over 50 years. Pyrethroids have considerably longer efficacy against RSB than the other available insecticide classes, but reduced efficacy and possible resistance have driven the need for insecticides that act upon unique target sites in RSB (Way and Tindall 2009).

Studies Conducted

Experiments were carried out from 2010 to 2013 to investigate multiple components of RSB integrated pest management (IPM): insecticide recommendations, sampling efficiency, treatment thresholds, farmer practices, and improved educational tools. The first objective of this research was to assess the efficacy of several currently labeled insecticides and a newer product from the neonicotinoid family of insecticides on control of RSB. Experiments were carried out in the laboratory, small field plots, and commercial fields across Louisiana. Results from efficacy trials showed that the neonicotinoid insecticide was comparable to the popular pyrethroid products most commonly used by rice producers in Louisiana. Conversely, the organophosphate malathion was shown to be highly ineffective in small plot tests. Glass-vial bioassays showed elevated levels of pyrethroid tolerance in a Texas RSB population.

The second objective sought to evaluate the density-damage relationship for rice stink bugs feeding in rice. The efficiency of sweep-net sampling was first determined, using a mark-recapture study in small plots, to establish the necessary density for infesting caged rice plots. Cage studies were carried out in 2010-2012, and RSB were infested at levels estimated to be 1-20x current economic thresholds. No significant relationships among rice stink bug densities and measures of damage were seen.

Objective three was to assess the adoption of recommended IPM practices by rice-industry professionals in southern rice producing states and to create original internet-based delivery of extension recommendations for RSB management. Rice producers in Louisiana and Texas were shown to prefer the use of pyrethroid insecticides above all other labeled products for RSB control, and growers in Texas averaged more applications of pyrethroids than respondents in Arkansas and Louisiana. Seed treatments to combat rice water weevils have been adopted rapidly in all states surveyed.

These studies provide helpful guidelines for producers to utilize when making rice IPM decisions. Adopting new insecticides and halting the use of traditional products may require not only research based recommendations, but also the knowledge that other producers are following the most recent suggestions. Likewise, streaming video recommendations increase the effective delivery of information among the growing demographic of farmers who access rice production guidelines on smartphones and tablets. The combination of field-based IPM research, industry surveys, and digital education content contribute greatly to the mission of extension entomology by bringing research-based IPM information to producers outside the traditional classroom for the purpose of improving the content and quality of Louisiana agriculture for both farmers and consumers.

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CHAPTER 2. LITERATURE REVIEW

Distribution and Host Plants

The RSB is endemic to North America east of the Rocky Mountains as far north as Minnesota and in the Gulf Coast regions of the West Indies and Mexico (Sailer 1944). C.V. Riley first determined that RSB was a pest of rice in 1882. Rice stink bugs prefer rice, *Oryza sativa*, but they feed on graminaceous species like barley, rye, oats, sorghum, wheat, barnyardgrass, broomsedge, broadleaf signalgrass, vasey grass, bearded sprangletop, Johnsongrass, and giant crabgrass among others (Douglas 1939, Odglen and Warren 1962, Tindall). Length of stadia, fecundity, and rate of survival increase when insects feed on rice or average temperature increases (Nilakhe 1976).

Morphology and Life Cycle

Adult RSB are distinguished from other pentatomids by their smaller size, about 1 to 1.25 cm in length, light brown color, and pronated spines on the pronotum. The shield-shaped body of the RSB is the most defining characteristic of Pentatomidae. Adults live approximately 30 to 40 days, and during that time females can lay as many as 915 eggs under optimum conditions (Nilakhe 1976). Male and female RSB are similar in appearance, but females can typically be discerned by their larger body size and green egg-laden ovaries visible through the slightly opaque ventral abdomen (Douglas and Ingram 1942). About 25% of eggs laid by mated females are sterile (Nilakhe 1976), and actual field survival from egg to 5th instar nymph is approximately 37% in the absence of predators (Blackman et al. 2014). Fecundity is significantly higher when RSB are reared on rice than when reared on graminaceous weeds (Nilakhe 1976). Eggs, approximately 0.63 mm in diameter, are laid in double rows of approximately 10 to 60 on leaves, stems, and panicles of host plants and hatch in 4 to 8 days

(Ingram 1927, Douglas and Ingram 1942, Odglen and Warren 1962, Nilakhe 1976). The barrel shaped eggs progress from light green to red as they develop but turn black if parasitized (Douglas and Ingram 1942). Nymphs complete five instars in 15 to 28 days (Douglas 1939, Douglas and Ingram 1942, Rashid et al. 2006).

Male and female adult RSB begin overwintering simultaneously in clump grasses in October, but males emerge in April and May approximately 10 days before females. Mating rituals begin soon thereafter, as all female RSB are reportedly enter overwintering in a state of diapause (Douglas and Ingram 1942, Bowling 1964, Nilakhe 1976). Grass clumps (smutgrass, vaseygrass, and broomsedge) are ideal overwintering sites for adult RSB. Populations of RSB pass through multiple generations on graminaceous weeds before moving into heading rice (Way 2003).

Damage

The RSB has been considered a major pest of rice production in North America since it was first discovered by C.V. Riley (Riley 1882; Webb, 1920; Douglas, 1939; Douglas and Ingram, 1942; Sailer, 1944; Brook, 1953; Swanson and Newsom, 1962; Odglen and Warren, 1962; McPherson, 1982; Way, 1990). Rice stink bugs prefer rice, *Oryza sativa*, but also feed on graminaceous species like barley, rye, oats, sorghum, wheat, barnyardgrass, broomsedge, broadleaf signalgrass, vasey grass, bearded sprangletop, Johnsongrass, and giant crabgrass among others (Douglas 1939, Odglen and Warren 1962, Tindall et al. 2004). However, they have lower fecundity and weight gain on most wild grasses, so feeding on rice increases rate of survival (Nilakhe 1976). Hamner determined that the shape of the alimentary canal varies substantially according to RSB diet (1936).

Rice stink bugs damage rice plants by feeding on both florets and developing kernels. Male and female RSB feed on developing rice grains beginning in the third instar (Naresh and Smith 1983,). Feeding increases the incidence of unfilled, broken, and discolored grains known as “pecky” rice in milled rice (Helm 1954; Swanson and Newsom 1963; Bowling 1963; Harper et al.1993; Tindall et al. 2005; Patel et al. 2006; Espino et al. 2007). Douglas (1939) described the damaged kernels as having “spots varying in color from a light yellow with a sort of bleached appearance to coal black.” Peck in rice samples can result in reduced purchase price and loss of income for producers (USDA-FGIS 2009).

Rice stink bug damage measured by determining the loss of yield or reduction in grade caused by rice stink bug feeding. Yield loss due to rice stink bug feeding is associated with insect feeding during the early stages of panicle development- from panicle emergence through the milk stage. During the latter two stages of grain filling, soft and hard dough, rice stink bug feeding results in chalky rice grains, broken grains, and pecky rice. These stages are often divided into two, two week periods. However, recent research suggests these schedules vary and more focus should be placed upon observed rice growth stages than the estimated week of panicle development (Awuni 2013).

Rice stink bug feeding on both rice florets and developing rice kernels from the R4 to R8 stages (Counce et al. 2000) of panicle development causes several distinctive types of grain damage, which may result in significant economic loss for producers. To extract nutrients from the developing grains of host plants, rice stink bugs insert their piercing-sucking mouthparts into the seed and inject salivary enzymes that allow grain contents to be dissolved and extracted through a stylet sheath (Bowling 1979). Injured florets result in blank rice grains, which are removed during harvest and dehulling and realized as lower rough rice yield. RSB feeding after anthesis can result in kernel damage manifested as discolored kernels, chalky kernels, broken kernels, and reduced kernel weight (Douglas & Ingram 1942). The discolored kernels, known as pecky rice, are the combined result of direct feeding damage and infection by pathogenic microorganisms transmitted to the developing grain during rice stink bug feeding in the milk and soft dough stages of panicle development (Douglas & Tullis 1950, Espino & Way 2006). Pecky rice is distinguished by characteristic bulls-eye lesions emanating from a small pin hole at the point of stylet insertion. Pathogens related to peck caused by RSB are: *Curvularia lunata, Bipolaris oryzae, Cercospora oryzae, Trichonis caudata, Fusarium oxysporum, Alternaria* spp., and *Nematospora coryli* (Daugherty & Foster 1966, Marchetti 1984, Hollay et. al. 1987).

Control Tactics

Cultural Control. Weed control and tillage are two major cultural control factors associated with infestation and IPM in all of the preferred host crops. Odglen and Warren (1962) determined that a correlation existed between barnyard grass present in and around rice fields and the amount of RSB present in the heading rice field. A nine-fold increase in RSB density was seen in plots containing high levels of both barnyardgrass and rice when compared to clean rice plots (Tindall et al. 2004). These findings reinforce the need for weed control early on in the development of the field as an important aspect of an integrated pest management (IPM) program. Delayed flooding to reduce populations of rice water weevils can allow establishment of various grassy weeds in the field and exacerbate RSB problems at heading (Tindall et al. 2004).

Varietal Resistance. Resistance differences exist between rice varieties, but the trend is a negative correlation between resistance and yield. John Bernhardt at the University of Arkansas Rice Research Extension Center has been collecting data on various varieties of rice for thirteen years to assist rice breeders with selection of varieties exhibiting RSB resistance. Results indicate that resistance increases with grain length. Those varieties with the least percent of discolored grains were not the highest yielding. The two leading varieties from the study are no longer produced today in Arkansas on the commercial market, but they continue to be studied to compare with contemporary varieties (Robinson et al. 1981, Bernhardt 2004).

Biological Control. Many natural enemies of the RSB have been documented. The parasitoid wasps *Ooencyrtus anasae* Ashmead and *Telenomus podisi* Ashmead were first reported to parasitize RSB eggs by Ingram (1927). Adult RSB are parasitized by the tachinid flies: *Beskia aelops* (Walker), *Cylindromyia euchenor* (Walker), *Euthera tentatrix* Loew, *Gymnoclytia immaculate* (Macquart) (McPherson and Mohlenbrock 1976), and *Gymnoclytia unicolor* (Brooks)(Thames 1954, Swanson 1960, Eger 1981, McPherson 1982); and a sand wasp *Bicyrtes fodiens* (Handlirsch) (Evans 1966). The fungus *Beauveria globulifera* Spegazzini has also been reported on RSB adults (Headlee and McColloch 1913). Eggs are preyed upon by several species of grasshoppers: *Conocephalus fasciatus fasciatus* (DeGreer), *Orchelimum laticauda* (Redtenbacher), *Neoconocephalus* spp., and *Melanoplus differentialis* (Thomas) (Louisiana). The green tree frog, *Hyla cinerea*, is also a common predator of the RSB in rice fields (Freed 1982). Red-winged blackbirds, *Agelaius phoenicius* L., were initially reported as predators of RSB (Douglas and Ingram 1942), but Borkhataria et al. (2012) found no significant difference in RSB levels between fields populated by *A. phoenicius* and controls. The birds *Sturnella magna, Cassidix mexicanus, and Bubulcus ibis* also reportedly feed on RSB (Genung et al. 1979).

Insecticidal Control. Chemical control of insecticides has been the primary recommended method over the years (Helm 1954 and 1955, Bowling 1962, McIlveen et al. 1981, Fryar et al. 1986, Johnson et al. 2003), although light traps have been suggested to reduce populations of RSB (Hill 2008). Insecticides labeled for use against rice stink bug before 2013 consisted of pyrethroids, organophosphates, and carbamates. However, the label for one organophosphate insecticide, methyl parathion, was rescinded in 2013 making it unavailable for rice farmers. The remaining labeled organophosphate, malathion, has had a history of ineffectiveness against RSB in rice (Bowling 1962, Way 1990). Acute toxicity assays conducted with rice stink bugs from multiple states have detected possible resistance to pyrethroids in Texas (Miller et al. 2010). A new chemical class was approved for use against RSB in Louisiana and Texas in 2013 that had previously been compared to pyrethroids in efficacy trials and reportedly had longer residual activity (Bernhardt 2009; Way et al. 2009). Neonicotinoids are considered to be less toxic than pyrethroids against non-targets and mammals (Tomazawa 2005).

Sampling

Sampling for RSB is currently recommended when 75% of panicles have emerged with the total sample area and continue on a weekly or biweekly basis. Timing of sampling is important because RSB seem to prefer feeding in the cooler temperatures during daylight hours. Samples taken at 0900 and 1900 hours are better than those taken around midday (Rashid et al. 2006). The most common method of sampling to determine total RSB numbers in a given area is normally done with a 15-inch diameter sweep net. Use of sweep nets for sampling RSB was first recommended by Helm in 1955. Bowling (1968) attempted to correlate visible RSB in the field with sweep counts.

Additional sampling methods have been investigated including the Tedders trap and the sweep stick sampling method. The Tedders trap is a simple contraption consisting of a yellow cone-shaped base of four vanes and a metal screen top to capture stink bugs drawn to the lure.

Stakes hold the trap firmly in the ground. Rashid, et. al, used a similar pyramid-shaped trap with various baits to compare with sweep net sampling. Results concluded that traps may prove useful in signaling movement of stink bugs to rice fields, but without placing traps in the middle of fields they cannot be used to measure density of RSB within the field (Rashid 2006).

Espino and Way (2008) measured the accuracy of sampling for RSB with a sweep stick rather than a sweep net. Justification for the study was that most consultants and farmers prefer a more convenient method than the traditional sweep net, and many farmers are reluctant to walk very far into a field to sample. Sweep sticks were suggested to simplify sampling for farmers and consultants.

Economic Thresholds

Thresholds established by Bowling in 1979 recommended treatment with labeled insecticides if 5 RSB are observed every 10 sweeps during the first 2 weeks of heading or if 10 RSB are counted per 10 sweeps during the latter 2 weeks. These thresholds were implemented throughout the southern US, except in Louisiana where the threshold was set at three insects per ten sweeps during the first two weeks of heading. In Texas, the initial thresholds were modified in 1988 (McIlveen), 1994 (Harper), and 2008 (Espino). Those 1994 guidelines took into account the plant stage, expected yield, market prices, insecticide application costs, and planting date (Harper 1994). The recommendations for sampling with a sweep stick are to treat if 3.2 RSB per sweep are seen during the first two weeks of heading or 6.6 insects are observed per sweep in the third and fourth week of heading (Espino 2008). Texas thresholds in 2014 included sequential sampling recommendations and an updated dynamic threshold that ranges from 8 to 34 RSB per 10 sweeps depending upon the heading stage and projected yield (Way 2014). Thresholds have remained the same in Arkansas and Missouri over the years, but Mississippi has recently reduced the RSB threshold to 3 insects per 10 sweeps during the anthesis and milk stages of panicle development (Gore personal communication).

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CHAPTER 3. COMPARISON OF THE EFFECTS OF NEONICOTINOIDS AND PYRETHROIDS AGAINST *OEBALUS PUGNAX* (HEMIPTERA: PENTATOMIDAE) IN RICE

Introduction

The rice stink bug (RSB), *Oebalus pugnax* (Fabricius) (Hemiptera: Pentatomidae), is an economically important late-season pest of rice (*Oryza sativa* L.; Poales: Poaceae) in the southern United States (Riley 1882; Ingram 1927; Douglas and Tullis 1950; Lee et al. 1993). Rice stink bug adults emerge from overwintering in the spring, and populations pass through multiple generations on graminaceous weeds before moving into rice when panicles emerge (Way 2003). Nymphs and adults feed on developing rice grains from anthesis until grain hardening. Feeding increases the incidence of unfilled, broken, and discolored grains known as "pecky" rice in milled rice (Helm 1954; Swanson and Newsom 1962; Bowling 1963; Harper et al.1993; Tindall et al. 2005; Patel et al. 2006; Espino et al. 2007). Peck in rice samples can result in reduced purchase price and loss of income for producers.

Insecticides labeled for use against rice stink bug before 2013 consisted of pyrethroids, organophosphates, and carbamates. Insecticides in the pyrethroid class (Table 3.1) have been labeled for rice stink bug management for more than 15 yr (EPA 1997; Schultz 2004; Delta Farm Press 2004). Recent surveys show that λ-cyhalothrin (Karate Zeon®, Syngenta Crop Protection, Greensboro, NC) and ɣ-cyhalothrin (Mustang® Maxx, FMC, Research Park Triangle, NC) are the primary products used against rice stink bugs in Louisiana and Texas (Blackman et al. unpublished). However, recent acute toxicity assays conducted with rice stink bugs from multiple states have detected possible resistance to pyrethroids in a south Texas rice stink bug population that typically receives multiple applications of pyrethroid insecticides (Miller et al. 2010b).

The organophosphates malathion and methyl parathion are less expensive than pyrethroids and can be applied closer to the time of harvest, factors that have contributed to their continued use against rice stink bugs. However, the Environmental Protection Agency (EPA) has rescinded the labels for methyl parathion products effective on 31 Dec 2013, and the product will no longer be available for use in the United States thereafter. The continued use of malathion is also in question because it has been shown to be significantly less effective against rice stink bugs than pyrethroids (Johnson et al. 2003; Blackman and Stout unpublished).

With the removal of methyl parathion, ineffectiveness of malathion, and indications of increased tolerance or resistance of rice stink bugs to pyrethroids, a new class of insecticides is needed to give producers additional options for rice stink bug management and prevent selection for pyrethroid-resistant populations. The EPA issued a full label for the neonicotinoid insecticide dinotefuran (Tenchu® 20SG, Mitsui Chemical Agro, Inc., Tokyo) (Table 3.1) to be used against rice stink bugs in rice in Louisiana and Texas in 2013, after several years of Section 18 Emergency Exemptions for the insecticide. Neonicotinoids act at nicotinic acetylcholine receptor sites in insects and are especially effective against piercing-sucking insects like rice stink bugs due to their ability to cross plant membranes and translocate throughout plant tissue where they are readily ingested (Tomazawa and Casida 2005). Neonicotioids have also been found to be considerably less toxic to *Procambrus* sp. crayfish than pyrethroids or organophosphates when applied to fields managed in the crayfish-rice rotation system common to Louisiana and Texas (Barbee & Stout 2009; Lanka and Stout unpublished data).

Table 3.1 Insecticides and rates used for small plot insecticide trials, 2011-2013.

PRODUCT	MANUFACTURER (Location)	ACTIVE INGREDIENT	A.I. RATE
Centric 40 WG	Syngenta (Greensboro, NC)	thiamethoxam	61.41 g/ha
Endigo 2.06 ZC	Syngenta (Greensboro, NC)	λ-cyhalothrin + thiamethoxam	90.15 g/ha and 108.18 g/ha
Karate Zeon*	Syngenta (Greensboro, NC)	λ-cyhalothrin	33.63 g/ha
Tenchu*	Mitsui Chemicals Agro, Inc. (Tokyo, Japan)	dinotefuran	125.8 g/ha

Dinotefuran has been reported to exhibit longer residual effects against rice stink bugs than pyrethroids in studies in Arkansas and Texas (Bernhardt 2009; Way et al. 2009). Our study sought to compare the merits of dinotefuran to those of pyrethroid insecticides. Experiments were carried out: to test the hypothesis that dinotefuran has a longer residual effect than λ-cyhalothrin on the mortality of adult rice stink bugs; to compare feeding damage on commercial fields treated with pyrethroids and neonicotinoids; to determine reinfestation levels in small plots and commercial fields treated with either insecticide, to compare adult rice stink bug feeding behavior on rice treated with pyrethroids and neonicotinoids, and to develop baseline LC_{50} data for pyrethroids on select populations of rice stink bugs in Louisiana and Texas.

Materials and Methods

Location and Rice Culture. Small plot field experiments were conducted at the Louisiana State University Agricultural Center Rice Research Station (RRS) in Rayne, LA in 2011, 2012, and 2013. The soil type at this location was a silt loam (fine, montmoillonitic, thermic, Typic Albaqualf). Plots of rice, 1.5 m × 5.5 m, were drill-seeded at 67.25 kg/ha and managed following LSU AgCenter recommendations for fertilization and control of weeds and pathogens (Blanche et al. 2009). Rice plots at this location typically become infested by rice stink bugs at levels exceeding current thresholds shortly after heading begins.

Insecticide Efficacy Trials. Experiments in 2011 and 2012 compared the effects of pyrethroids, neonicotinoids, and neonicotinoid/pyrethroid combinations on densities of rice stink bugs in small plots. Treatments consisted of an untreated control and 4 insecticides: λ-cyhalothrin, λ-cyhalothrin + thiamethoxam, thiamethoxam, and dinotefuran (Table 3.1). Treatments were applied to the plots of rice cultivar "Cocodrie", a widely grown long-grain cultivar. Plots were arranged in a randomized block design with 4 replications. Plots were separated by 1.2 meters on all sides.

In 2013, an experiment similar to the 2011 and 2012 experiments was conducted using the rice cultivar "Cheniere", another widely grown long grain cultivar. Treatments for the 2013 experiment were the same as those in 2011 and 2012 (Table 3.1) except for the substitution of a second high rate of λ-cyhalothrin + thiamethoxam (439 mL/ha) in place of thiamethoxam. Treatments were again assigned to plots according to a randomized block design with 4 replications. The arrangement of plots was changed from previous years to improve treatment spacing. The number of rice plots in each block was doubled, but treatments were applied to every other plot so that treated plots were surrounded on all sides by untreated plots.

Treatments were applied when rice in plots had reached 75 to 100% panicle emergence and stink bug populations exceeded the current threshold of 3 adults per 10 sweeps. All insecticide solutions were prepared in a laboratory using tap water (pH 7.66) as a carrier and applied between 0730 and 0800. Treatments were applied using a backpack, CO_2-powered sprayer calibrated to deliver 140.5 L/ha. Plots were sampled at multiple time points after application by making 10 consecutive sweeps across each plot with a 15-inch (38.1 cm) diameter sweep net. Numbers of rice stink bug adults and nymphs caught in sweep nets in each plot were recorded in the field separately, but life stages of individual nymphs were not recorded.

Repeated measures analyses were conducted in SAS using PROC GLIMMIX to compare the effects of treatments on rice stink bug densities in plots at various time points after application (SAS 2008). The block and treatment x block variables were considered random in the analysis. Means were compared using Tukey's HSD. Analyses were conducted separately for nymphs and adults for each year.

Comparison of Residual Activities. An experiment was conducted in 2011 to test the hypothesis that dinotefuran has longer residual activity than λ-cyhalothrin when both insecticides are applied at label rates. Small plots of rice (cv. 'Cocodrie') were planted and cultured as described above. At heading, treatments of λ-cyhalothrin [44.83 g (AI)/ha], dinotefuran [126 g (AI)/ha], and an untreated control were assigned to plots according to a randomized block design with 4 replications.

Adult rice stink bugs were confined to rice panicles at two time points following insecticide application and their mortality assessed 48 h later to compare residual activities of dinotefuran and λ-cyhalothrin. Stink bugs were confined to panicles using tulle net cages measuring 34 cm × 10 cm. Adult rice stink bugs were collected with sweep nets from untreated grassy weeds and rice at the RRS. Collected insects were temporarily held in aluminum cages with fresh rice and grassy weed panicles for approximately 30 minutes. They were held at 4.5 °C for 15 min to reduce mobility and prevent escape during transfer to nylon sleeve cages. Insects with no visible signs of damage were transferred to cages and confined to the top quarter of the cage with twist ties (Sturdy-Twists, Woodstream Corporation, Lititz, Pennsylvania) for ease of transfer to panicles and to prevent escape during sleeve installation . Cages provided adequate room for insects to feed on all areas of the panicle.

Cages with bugs were transported to the field, placed over individual panicles, and secured at the panicle base using twist ties. Four stink bugs were confined to each cage and 3 cages were placed in each plot at 2 h and 144 h after insecticide applications. Furthermore, to ensure that insecticides had been applied effectively, a single sleeve cage with 3 stink bugs was placed over 1 panicle in each plot before spraying, and mortality was recorded 2 h after spraying. For the cages placed at 2 and 144 h, cages were removed to assess mortality after 48 h. Panicles with cages and insects were detached from the plant below the twist tie and brought back to the lab. Total insects alive and dead were assessed within 30 minutes of removal from the field. Insects were considered dead when they were observed motionless for 15 seconds after being prodded with a sharpened pencil.

Proportions of insects surviving in each cage were calculated and analyzed using PROC MIXED in SAS (SAS 2008). Comparisons of the effects of treatments on the proportion of insects surviving on each day were done by pair-wise *a priori* contrasts. To estimate appropriate degrees of freedom, Satterthwaite's adjustment of degrees of freedom was used in the model statement.

Acute Toxicity Bioassays. Assays were conducted in 2013 to compare the LC_{50}s of λ-cyhalothrin for rice stink bugs from 2 populations with differing histories of pyrethroid use. As an initial step, baseline LC_{50} and LC_{95} values were established using a population of rice stink bugs collected from the RRS. Serial dilution vial bioassays (0-10µg/mL) were prepared following Miller et al. (2010), and assays were conducted on groups of stink bugs on 3 Aug, 31 Aug, and 1 Sep (total n = 990). For each assay, 1 adult insect was placed into each vial and caps were lightly secured on vials to ensure they were not airtight. Insects were assessed for mortality after 4 h exposure. To assess mortality, insects unable to right themselves in vials were placed on a petri dish and observed for 15 s. If they did not right themselves and remain in an upright position within the allotted time, they were considered dead. Data from the 3 collection dates were pooled, and the LC_{50} and LC_{95} were determined using SAS PROC PROBIT (SAS 2008). For subsequent assays, vials were prepared using the LC_{50} and LC_{95} values determined from these initial assays. Analysis of subsequent assays was performed by comparing adjusted percent mortality of each population and treatment level to fiducial limits and confidence intervals in baseline assays. Abbot's Formula was used to correct for control mortality in the RRS population.

Subsequent bioassays compared mortalities at the LC_{50} and LC_{95} concentrations of rice stink bugs collected from the RRS on 26 Sep and from a site in Wharton County, Texas (N 29° 12.498'; W 96° 29.988') on 9 Oct. The former site was an area of relatively light pyrethroid use, whereas the latter was recently suspected of harboring a resistant population of rice stink bugs (Way 2011). Vials were prepared on 25 Sep for both bioassays.

Insects were collected from rice fields and neighboring areas containing headed barnyard grass and broadleaf signalgrass. Insects were transferred to aluminum cages (Bioquip #1450B) and then transported to the lab where assays were initiated. Insects used in Louisiana tests were held for 12 h before assays, while insects for Texas assays were held for approximately 1 h. Special attention was given to ensure caged insects were kept out of direct sunlight and had an adequate water source via moistened cotton balls or paper towels. At the RRS, 40 vials for control (no insecticide), LC_{50} (0.297 ppm) and LC_{95} (9.772 ppm) concentrations were infested with a single adult rice stink bug. In Wharton County, 60 insects were used for the control and

LC_{50} treatments, and 59 were used for the LC_{95} population. Insects at both locations were assessed for mortality (as stated above) after 4 h exposure.

Behavioral Effects of Insecticides. Experiments were conducted in 2011 and 2012 to assess potential sub-lethal effects of λ-cyhalothrin and dinotefuran on adult feeding behavior. Whole rice plants, from untreated plots or plots treated with λ-cyhalothrin and dinotefuran at 44.83 g/ha or 126 g/ha, respectively, were uprooted 2-4 hours post treatment and placed individually in plastic 5-gallon (18.9 L) buckets. Buckets containing plants were transported inside an air-conditioned truck cab to a greenhouse on the campus of Louisiana State University, where they were stored for 72 h before the start of the experiment. Feeding behavior was monitored in polystyrene petri dishes (14 cm diameter and 2.2 cm depth, Corning™ New York). Petri dish bottoms contained approximately 0.5 cm layer of 2.0% agar to maintain moist conditions. The distal end of panicles was excised, and the 6 cm cut end containing 10-15 spikelets was inserted into the agar bed. Two of these panicle portions were placed in each petri dish: 1 panicle portion from an untreated plant and 1 panicle portion from a plant treated with either dinotefuran or λ-cyhalothrin. Ten petri dishes for both dinotefuran and λ-cyhalothrin treatments were used to compare stink bug feeding behavior on treated and untreated panicles. A third group of Petri dishes contained 2 spikelets from untreated panicles.

Feeding assays were initiated by releasing 1 adult rice stink bug in each petri dish. At several time points after experiment initiation, observations on feeding and non-feeding related behaviors were recorded for 1 minute. The extension of stylets to contact with a grain on a panicle was categorized as feeding-related behavior. All other activities, such as antennal brushing, rubbing of legs, and running and walking toward or away from panicle, were categorized as non-feeding behaviors. Observations of behaviors were made at 8 (2011) or 9

(2012) time points. Three observations were made within 1 h of test initiation and successive observations were made at 3 h intervals thereafter.

The numbers of occurrences of feeding and non-feeding behaviors in petri dishes at each time point were converted into percent time for each of the two behavioral categories. Analysis of variance was conducted on untransformed data using percent time as the dependent variable and insecticide treatment as the independent variable. Post hoc comparisons were done by using Tukey comparisons between each category of behavior in λ-cyhalothrin and dinotefuran treatments and in untreated controls.

Demonstration Trial. Demonstration tests were conducted to compare the efficacies of dinotefuran and registered pyrethroids (λ-cyhalothrin or z-cypermethrin) under commercial growing conditions. Nine commercial field sites were selected in 7 Louisiana parishes in the northern, central, and southwestern rice-growing regions of the state (Table 3.2). Each field site comprised 2 adjacent fields of similar area, all greater than 1 hectare**,** which could be treated by aircraft. Adjacent fields had been planted with the same variety and were managed in an identical fashion.

Table 3.2 Demonstration trial rice varieties and insecticide rates.

Plot Location	Variety
Jeff Davis Parish	XL CL729
Acadia Parish 1	Cheniere
Acadia Parish 2	CL151
Acadia Parish 3	CL151
Acadia Parish 4	CL131
Acadia Parish 5	CL161
Avoyelles Parish	Cheniere
Concordia Parish 1	NA
Concordia Parish 2	NA
Morehouse Parish 1	CL151
Morehouse Parish 2	CL151
Morehouse Parish 3	XL CL729

Rice stink bug populations were monitored before and after insecticide treatment by sweeping 10 times at 10 different locations in each field, and feeding damage was evaluated by analysis of pecky rice in harvested rough rice. Sweep net sampling was conducted 24 to 48 h before spraying for each site between the growth stages of anthesis and hard dough. Post-treatment sweep net counts were taken at 48 h and 7 days after treatment to determine efficacies of treatments against infestation of adult rice stink bugs. The pyrethroid-treated field at the Morehouse Parish 2 site remained above threshold at the 48 hour sampling point and was treated with a second application of pyrethroid at 48 h to reduce infestation levels. This field was not included in the analysis for the 7 day sampling period. Samples of rough rice were collected from all 11 sites at harvest and analyzed by a USDA certified inspector at Louisiana Rice Mill in Crowley, Louisiana, to determine percent pecky rice.

Post-treatment sweep net sampling data were analyzed as repeated measures using the PROC MIXED procedure in SAS (SAS 2008). Tukey's HSD was used to determine significant differences at the $P = 0.05$ level. Field site was considered a random variable in the analysis. The impact of insecticide treatments on percent peck was analyzed by ANOVA with PROC GLIMMIX in SAS (SAS 2008).

Results

Insecticide Efficacy Trials. In 2011, densities of nymphs (nymphs per 10 sweeps) were significantly affected by insecticide treatment ($F_{4,12} = 18.22$; $P < .0001$). Significantly greater nymph densities were found in control plots than in plots of all other treatments at 1 and 2 days after treatment (DAT) (Figure 3.1a). Densities in control plots fell considerably between 2 and 5 DAT, and no significant differences were observed among treatments at 5 DAT. Insecticide treatment did not significantly affect adult densities in plots ($F_{4,15} = 1.85$; $P = 0.1714$) (Figure

3.1b). However, a significant treatment x day interaction was observed ($F_{8,30} = 2.57$; P = 0.0288). Among adult rice stink bug samples, densities in plots treated with thiamethoxam at 1 DAT and λ-cyhalothrin at both 1 and 2 DAT were lower than densities in controls.

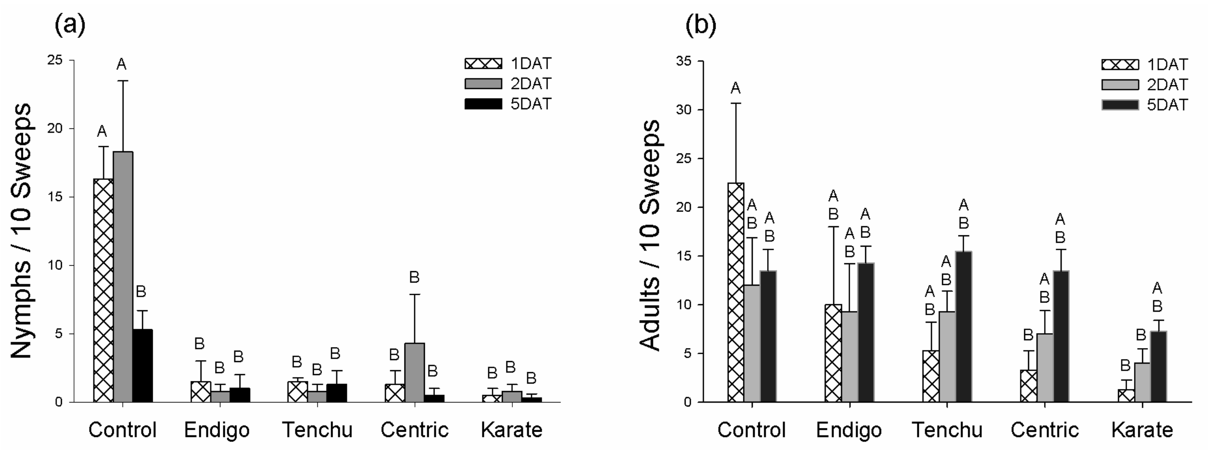

Figure 3.1 Mean ± SE rice stink bug nymphs (a) and adults (b) in 10 sweeps on untreated and insecticide treated rice small plots in 2011. Means accompanied by different letters indicate a significant difference ($P < 0.05$).

Insecticide treatment also affected nymph densities in plots in 2012 (Figure 3. 2a, $F_{4,42}$ = 22.42; $P < .0001$). Only the λ-cyhalothrin treatment significantly reduced nymphs at one DAT. Significant differences in nymph densities were detected between control plots and plots of all treatments at three and six DAT. All treated plots had nymph densities less than half the mean for untreated plots at each time point. Densities of adults in the 2012 experiment were lower than in 2011, and no significant differences were detected among treatments for densities of adults at any time point (Figure 3.2b, $F_{4,15} = 1.09$; $P = 0.3969$).

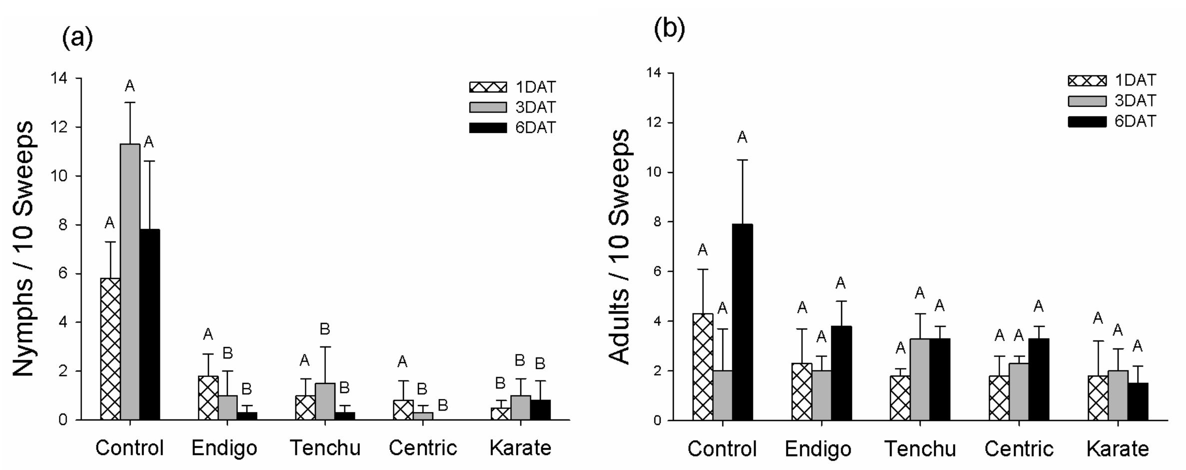

Figure 3.2 Mean ± SE rice stink bug nymphs (a) and adults (b) in 10 sweeps on untreated and insecticide treated rice small plots in 2012. Means accompanied by different letters indicate a significant difference ($P < 0.05$).

In 2013, a marginally significant difference was observed among treatments for nymph densities (Figure 3.3a, $F_{4,57} = 2.19$; $P = 0.0812$). No treatment was significantly different than the control at the $P = 0.05$ level for any sampling date. At one DAT, nymph densities remained below 1 insect per 10 sweeps in all treatments except the untreated control (3.00 ± 1.58) and λ-cyhalothrin (1.75 ± 1.81). Nymph densities remained low at 3 DAT (1.00 ± 0.71). Densities of adults were again low in 2013. As in 2012, no significant differences were observed between treatments in adult densities (Figure 3.3b, $F_{4,12} = 0.55$; $P = 0.6996$).

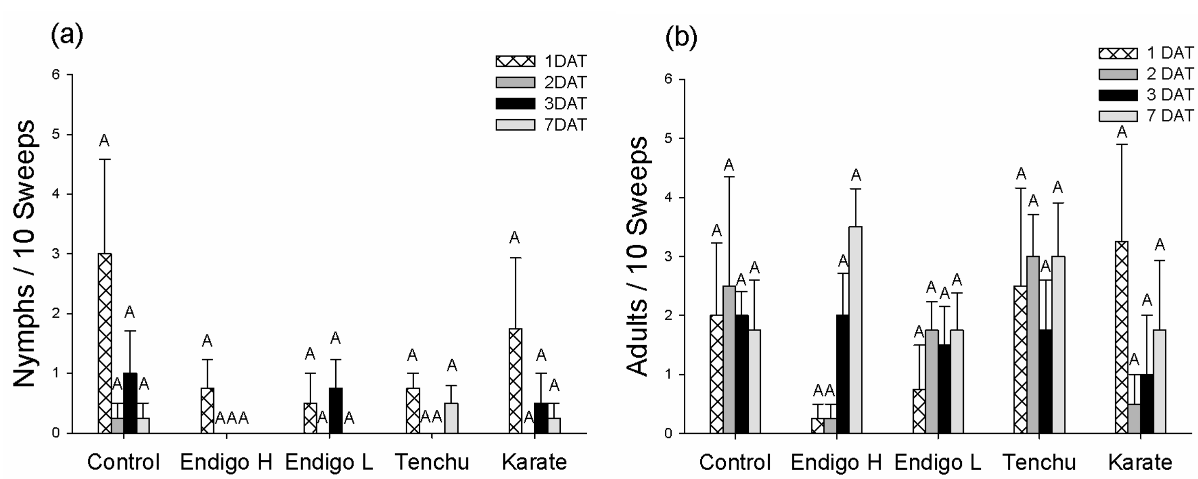

Figure 3.3 Mean ± SE rice stink bug nymphs (a) and adults (b) in 10 sweeps on untreated and insecticide treated rice small plots in 2013. Means accompanied by different letters indicate a significant difference ($P < 0.05$).

Comparison of Residual Activities. Contrasts showed a significant difference in rice stink bug mortality among treatments immediately after spraying ($F_{1,7.95}$ = 9.36; P = 0.0157), with approximately 80% mortality in the 2 insecticide treatments but only 10% mortality in controls (Figure 3.4). In bugs placed on panicles 2 h after treatment ($F_{1,30.7}$ = 15.56; P = 0.0004), survival was significantly lower on dinotefuran treated panicles than controls (P = 0.0068) but not on panicles treated with λ-cyhalothrin (P = 0.2722). No significant differences were observed among treatments at 144 HAT ($F_{1,24.6}$ = 0.25; P = 0.6188).

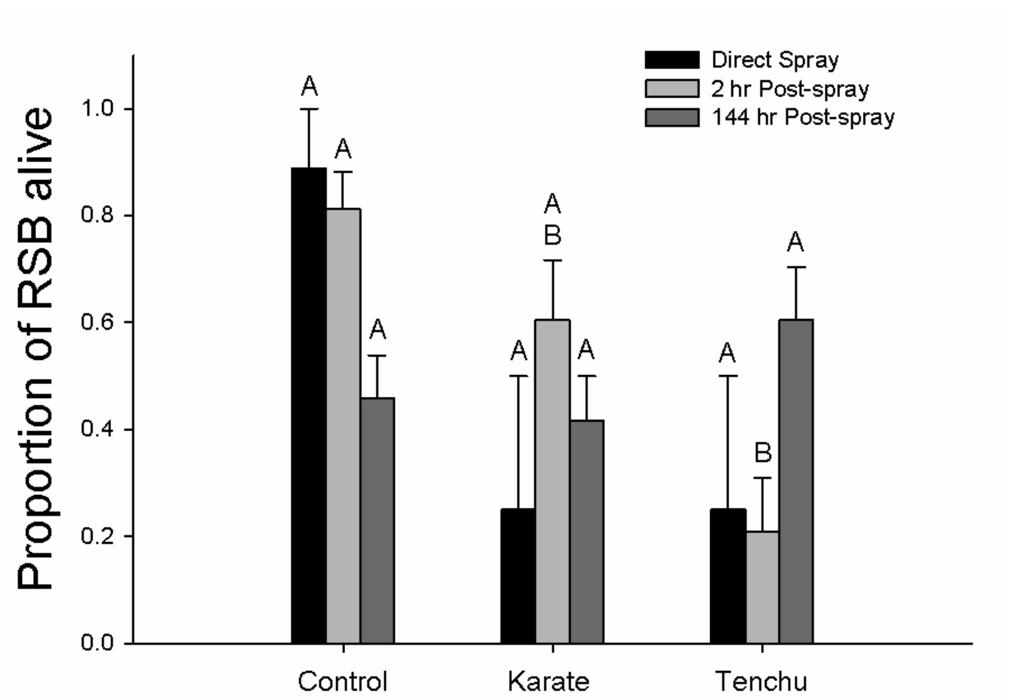

Figure 3.4 Mean ± SE proportion of RSB confined to sleeve cages at 3 time points after insecticide applications in 2011. Means accompanied by different letters indicate a significant difference (P < 0.05).

Acute Toxicity. Serial dilution assays with λ-cyhalothrin to determine baseline LC_{50} and LC_{95} values established that mortality of stink bugs collected at the RRS was dose dependent (P < 0.001; slope = 1.941 ± 0.3376) with an LC_{50} of 0.2973 ppm (CI: 0.1226-0.6883), an LC_{95} of 9.7723 ppm (CI:2.8364-184.2757), and a chi-square value of 33.06 (1.941 df). Subsequent comparisons of mortalities of bugs collected from the RRS and Wharton County using vials treated with the LC_{50} and LC_{95} concentrations showed a difference between the RRS and Wharton County populations. Mortalities of stink bugs from the RRS population at the LC_{50} concentration (72%) and the LC_{95} concentration (100%) were higher than the fiducial limits initially calculated from the baseline assays (35-65% and 85-98% for the LC_{50} and LC_{95} concentrations, respectively). In contrast, insects from Wharton County exposed to the same LC_{50} and LC_{95} concentrations exhibited only 15% and 66% mortality, respectively, values below the fiducial limits from the initial baseline assay. Thus, the population of rice stink bugs from Wharton County was more tolerant of λ-cyhalothrin than the population of stink bugs from the RRS.

Laboratory Feeding Assay. No insect mortality was observed in the feeding assay. The percent time spent feeding by rice stink bugs differed with insecticide treatment in both the 2011 (Figure 3.5a. $F_{2, 27} = 5.3$; $P = 0.01$) and 2012 (Figure 3.5b $F_{2, 27} = 6.0$; $P = 0.007$) experiments. In 2011, the proportion of time spent feeding by rice stink bugs in the control treatment (in which both panicles in dishes were untreated) was significantly higher ($P = 0.01$) than in the dinotefuran treatment (1 untreated panicle, 1 dinotefuran panicle) but was not significantly higher than the feeding time in the λ-cyhalothrin treatment (1 untreated panicle, 1 λ-cyhalothrin panicle) (P = 0.1). No significant difference was found between λ-cyhalothrin and dinotefuran treatments. Consistent with results from 2011, stink bugs in control dishes in the 2012 experiment spent a significantly greater proportion of time feeding in the control treatment than in the dinotefuran ($P = 0.009$) or λ-cyhalothrin ($P = 0.03$) treatments in the 2012 experiment. Once again, no significant difference was found between λ-cyhalothrin and dinotefuran treatments in 2012.

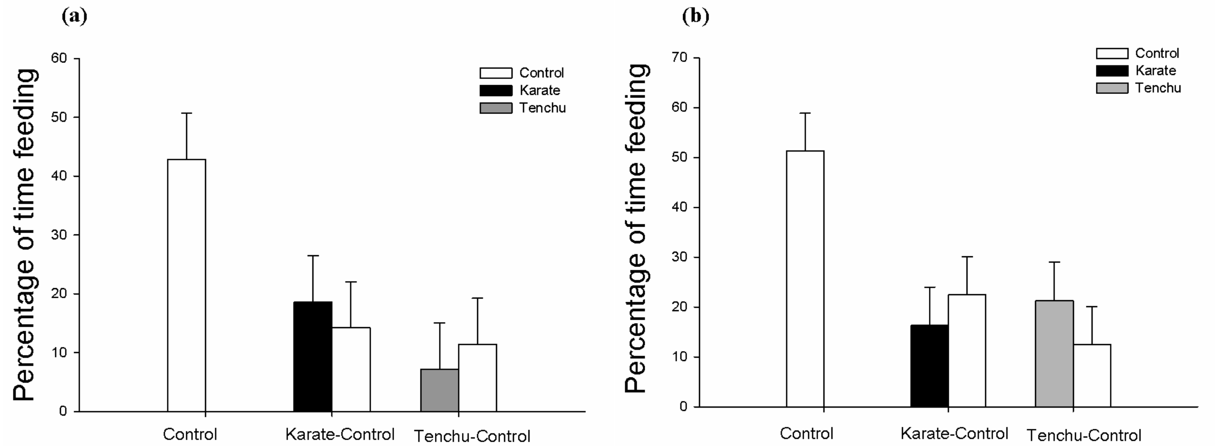

Figure 3.5 Mean ± SE time spent feeding on treated and untreated rice panicles in choice experiments in 2011 (a) and 2012 (b).

Demonstration Trial. Significant differences in *O. pugnax* densities were observed for treatment ($F_{1,46}$ =13.85; P = 0.0005) and day ($F_{2,46}$ < 0.0001) but not in the treatment x day ($F_{2,1}$ = 7.20; P = 0.2548) type III tests of fixed effects. No significant difference was seen between pyrethroid and dinotefuran treatments at any sampling date (Figure 3.6). A reapplication of pyrethroid was required to reduce *O. pugnax* populations below threshold at 1 of the sites, but no reapplication was necessary for the adjacent field treated with dinotefuran. Because of the reapplication, this site was not included in the 7 DAT comparison analysis. Fields treated with dinotefuran had a lower (P = 0.08) mean percentage of pecky rice in milled samples (0.4, n = 9) than λ-cyhalothrin treated fields (0.5, n = 9) (Figure 3.7).

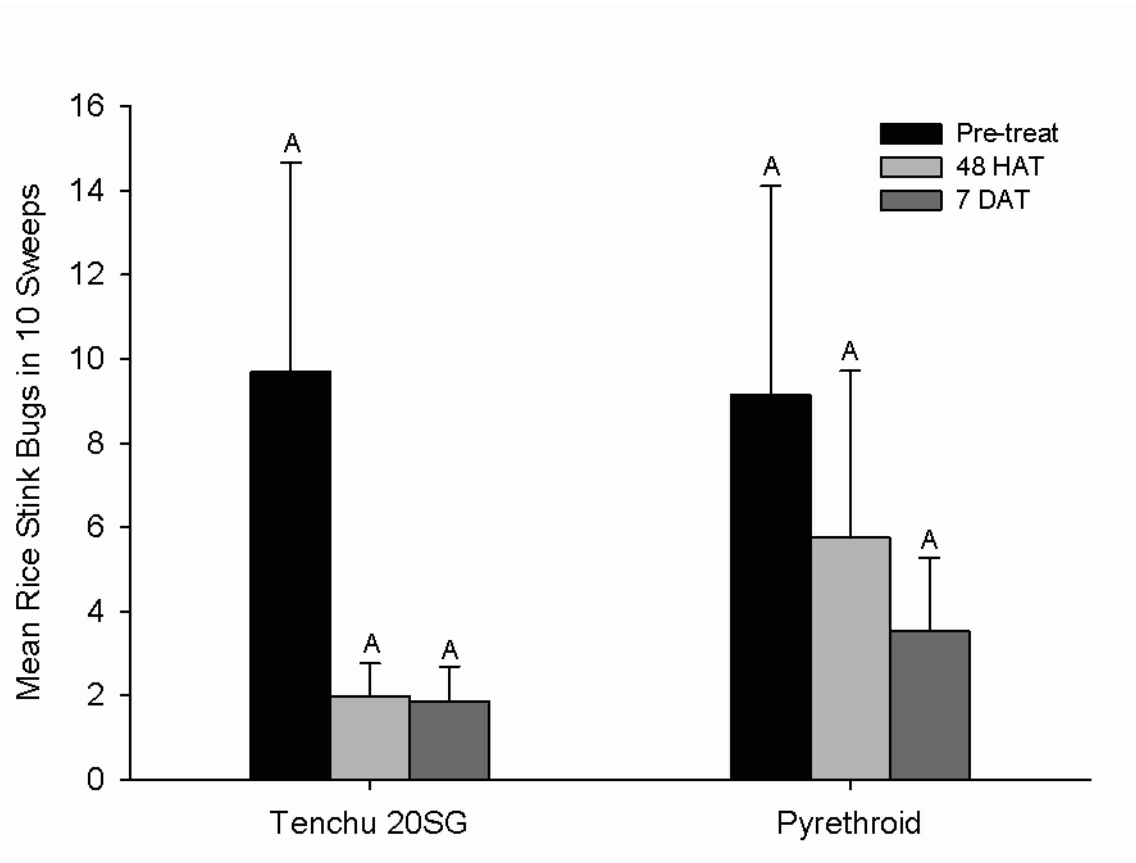

Figure 3.6 Average rice stink bugs caught in 10 sweeps in commercial fields treated with a pyrethroid or dinotefuran.

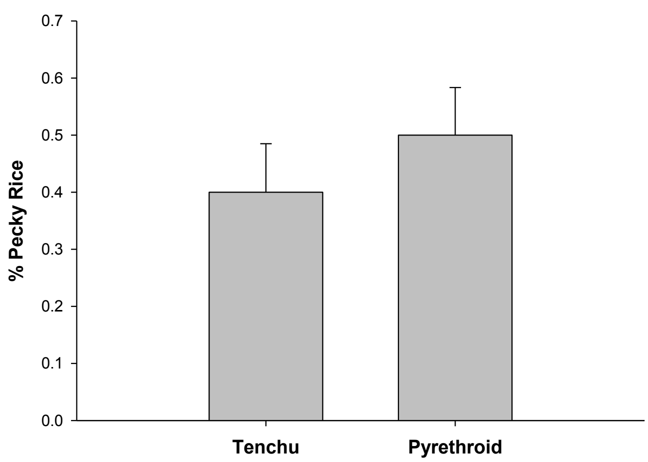

Figure 3.7 Percent pecky rice in samples treated with Tenchu and pyrethroid in 2011. No significant difference was seen between treatments.

Discussion

Insecticide applications remain the primary management tactic for reducing rice stink bug populations in all affected rice growing states, and pyrethroids (including λ-cyhalothrin) are the most widely used insecticides (M. Stout and B. Blackman, unpublished data). Recently, the neonicotinoid insecticide dinotefuran has been registered for rice stink bug management in the southern U.S. Densities of *O. pugnax* adults were not significantly affected by applications of either λ-cyhalothrin or dinotefuran at any time point in the small-plot insecticide efficacy trials, although densities tended to be lowest in in plots treated with λ-cyhalothrin at most time points. In contrast, in the commercial demonstration trials, applications of insecticide significantly reduced densities of rice stink bugs, with dinotefuran providing a marginal advantage ($P < 0.1$) over λ-cyhalothrin at reducing percent pecky rice in milled samples. Furthermore, in the small-plot trials, densities of *O. pugnax* nymphs differed significantly among control and treated plots for all insecticides and time points in 2011 and 2012, and both λ-cyhalothrin and dinotefuran were effective at maintaining average nymph populations at approximately 1 per 10 sweeps.. The contrasts between the results of the small-plot and commercial trials and between the results for nymphs and adults in the small plot trials point to the important influence of adult movement on the results of these experiments. Movement of large numbers of adult rice stink bugs into commercial fields after insecticide treatments was far less likely than was migration of adults into treated plots in the small-plot experiments, where treated plots were in close proximity to large areas of untreated rice. Similarly, migration of large numbers of wingless nymphs into treated plots was probably minimal, as nymphs remain aggregated within fields until adulthood (Reay-Jones 2010). Thus, the results of both the commercial demonstration trials and nymph sampling in small plots provide insights into the efficacies of insecticides not provided by monitoring densities of adult stink bugs, the standard practice. Overall, the results of the insecticide trials suggest that the efficacies of dinotefuran and λ-cyhalothrin against *O. pugnax* are comparable.

In the residual cage experiment, rice stink bug adults confined to panicles in sleeve cages and directly exposed to λ-cyhalothrin and dinotefuran experienced high levels of mortality compared to controls. More importantly, bugs confined to dinotefuran-treated panicles but not λ-cyhalothrin-treated panicles showed higher levels of mortality than controls at 2HAT. Results at 144 HAT were obscured by high levels of mortality in control cages; the reasons for this high mortality are unknown but are probably related to adverse environmental conditions at the time of the experiment. Limiting the confinement of insects to cages to 24 hours may help reduce control mortality in future experiments of this kind. Nevertheless, the results of the cage study reported here are similar to those reported by Way et al. (2009), who found significantly higher mortality of rice stink bug adults feeding on rice panicles treated with dinotefuran than on panicles treated with λ-cyhalothrin. Thus, dinotefuran may possess longer residual activity than λ-cyhalothrin; this possibility must be explored further.

Rice producers in Southeast Texas often spray more pyrethroid applications to maintain rice stink bug populations below economic thresholds than farmers in surrounding states (Smith 2010; Way 2011). Results of vial bioassays in this study were consistent with the suggestion that consistent rice stink bug exposure to pyrethroids like λ-cyhalothrin is contributing to resistance development in populations of Southeast Texas. New insecticides like dinotefuran must be brought to market to conserve susceptible genes in rice stink bugs and prevent the resistance caused by continued insecticide applications that act on a single target site in the rice stink bug.

The feeding assay in which bugs were given a choice of treated and untreated panicles allowed the detection of previously undocumented effects of insecticides on the behavior of this insect. Rice stink bugs spent a smaller percentage of their time feeding when placed in petri dishes with dinotefuran treated panicles (2011 and 2012) and λ-cyhalothrin treated panicles (2012), even though untreated panicles were available. The results of this choice assay are consistent with observations made of rice stink bugs feeding on dinotefuran-treated rice. Adult *O. pugnax* feeding on dinotefuran treated panicles in the lab, experimental small plots, and commercial fields sometimes appeared extremely lethargic. These insects were observed grasping onto panicles, but they were unresponsive to prodding with a fingertip. This behavior was observed at later sampling dates, suggesting that dinotefuran affects insect feeding behaviors differently than λ-cyhalothrin after the initial application. Experiments need to be designed and conducted using confined insects feeding solely on treated panicles to further document these behavior and the effect it may have on fecundity and development of rice stink bugs.

The combination of these experiments shows that neonicotinoids, notably dinotefuran, provide effective control of rice stink bugs when compared with currently labeled products. From the standpoint of reducing populations and deterring feeding of rice stink bugs, dinotefuran appears to be equivalent if not slightly more effective than λ-cyhalothrin. Safer and effective insecticides with varying modes of action targeting rice stink bug are needed to relieve the selection for resistance resulting from the widespread application of pyrethroids for rice stink bug control throughout the Southern US rice-growing region. Dinotefuran exhibits a low mammalian toxicity (LD50= 1,000-3,000 mg/kg) (EPA 2004), while λ-cyhalothrin is considered moderately toxic to mammals (56 mg/kg)(EPA 1988). Dinotefuran also differs from λ-cyhalothrin in that it acts at a different target site on the rice stink bug than pyrethroids like λ-cyhalothrin. Widespread adoption of dinotefuran among rice IPM programs across the southern rice-producing states will benefit producers and consumers by reducing total insecticide applications and subsequent costs for *O. pugnax* control, as well as delaying resistance development in *O. pugnax* populations.

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CHAPTER 4: COMPARISON OF MALATHION, KARATE Z AND TENCHU 20SG AGAINST RICE STINK BUG

Introduction

Malathion has been recommended for control of rice stink bugs (RSB) in headed rice for over fifty years in the southern United States. During that time, application rates have almost doubled due to increased tolerance of RSB to the insecticide. The pesticide was initially considered effective to reduce adult rice stink bug populations for a 48 hour period when applied at the rate of 0.56 kg(A.I.)/ha in 1962. It was reevaluated in 1972 at the rates of 0.56 kg(A.I.)/ha and 0.84 kg(A.I.)/ha at one and seven days after treatment by Oliver et al. Those tests concluded that both rates of malathion were effective at controlling rice stink bug adults and nymphs at 1DAT. Results from the 7DAT time point were inconsistent and control above 69% was only seen in adults at the lower rate. The recommended field rate of 0.56 kg(A.I.)/ha was increased to the current recommendation of 1.01kg(A.I.)/ha prior to 1987. In studies conducted before and after the recommended field rate increase, malathion was never considered to exhibit residual activity against the pests beyond 48 hours (Bowling 1962, Way 1990). Surveys conducted by the Louisiana State University Agricultural Center and Texas A&M University AgriLife show that rice farmers in those states were still using malathion in 2012 for the control of rice stink bugs (Blackman et al. unpublished).

In 2012, the efficacies of malathion (organophosphate, Gowan Malathion 8F), Karate Z (pyrethroid, A.I. lambda-cyhalothrin, Syngenta Crop Protection), and Tenchu 20SG (neonicotinoid, A.I. dinotefuran, Mitsui Chemicals, Inc.) were compared in small plot studies against the RSB. These three insecticides represented the three most popular insecticide classes used by rice farmers in Louisiana and Texas to manage rice stink bug populations between 2008 and 2012 (unpublished). A 2013 experiment again compared malathion at the labeled rate and a higher rate with Karate Z and a pyrethroid unlabeled for rice stink bug control, Fastac EC (A.I. α-cypermethrin, BASF).

Materials and Methods

Experiments were carried out at the Louisiana State University Agricultural Center Rice Research Station in Crowley in a Crowley silt loam soil. Plots of rice, 1.5 m x 5.5 m, were drill-seeded and managed following LSU AgCenter recommendations for fertilization and control of weeds and pathogens (Blanche et al., 2009). Treatments were applied using a CO_2 powered backpack sprayer.

2012 Experiments- September 2. Rice variety CL 151 was drill-seeded at a rate of 355 seed per square meter on March 18th, harvested on July 30th, and flail mowed (to encourage uniform panicle regrowth). Treatments were applied in a randomized block design to plots (1.5m x 4.5m) of second-crop rice at the 75% headed stage on September 2nd. Insecticide treatments included Karate Z foliar application, 0.045 kg (A.I.)/ha (0.04 lb/a), Tenchu 20SG foliar application, 0.103 kg (A.I.)/ha (label recommends 7.5-10.5 oz/acre), malathion 1.01kg (A.I.)/ha (0.9 lbs/ac), and an untreated control. Plots were swept ten times with a 38 cm sweep net at one, three, and six days after treatment (DAT) and the number of rice stink bug adults and nymphs was recorded.

2012 Experiments- September 14. Treatments were applied in adjacent plots on September 14th when the rice was entering the milk stage (R5). Sampling occurred at one, four, and six days after treatment.

2013 Experiments- August 14. Rice (cv. Cheniere) was drill-seeded at a rate of 67 kg/ha. Malathion was applied at the highest labeled rate, 1.01kg a.i./ha (0.9 lbs/ac), and at an extra-label rate of 1.68kg a.i./ha (1.5 lbs a.i./ac). Rates for Karate Z and Fastac were 0.045 kg

(A.I.)/ha (0.04 lbs a.i. per ac) and 0.023 kg (A.I.)/ha (0.02 lbs a.i./ac), respectively. Rice plots in the milk and soft dough stages of panicle development were treated in a randomized block design across four replications on August 14 at 0900 hours. One plot in each replication was left untreated. Plots were sampled at 2 hours, 2 days, and 5 DAT.

Data Analysis. Data were analyzed as repeated measures mixed model ANOVA using PROC GLIMMX in SAS. Data were pooled for 2012 experiments, but years were analyzed separately. Treatment and time were fixed effects and block were random effects in the model. In addition, data from each sampling point were analyzed individually using PROC GLIMMX with treatment as a fixed effect and block as random effect. Means were separated using Tukey's HSD test.

Data in 2013 were analyzed in the same manner as the 2012 data.

Results

2012. Effect of treatment was significant at the $P<0.1$ value, ($P=0.07$; $DF= 3,21$; $F=2.69$), but effects of DAT ($P=0.69$; $DF= 2,56$; $F=0.37$), and treatment x DAT ($P=0.88$; $DF= 6,56$; $F=0.40$) were not significant. Karate and Malathion were the only treatments significantly different from one another in Tukey's HSD test (Table 4.1). No treatments were significantly different from the control. The mean number of rice stink bugs in 10 sweeps remained below the recommended action threshold for both tests, and the greatest difference between treated and untreated plots was seen in the comparison of Karate Z (3.96 insects) and both the control and malathion plots (7.13 insects) at 1 DAT (Figure 4.1, Table 4.2).

Table 4.1 2012. Mean rice stink bug adults caught in each treatment over all three sampling times in both experiments. Different letters denote significant difference at the P=0.1 level.

Treatment	Mean RSB in 10 Sweeps over three sampling dates
Untreated Control	6.63 ± 3.03ab
Karate Z, 0.045 kg (A.I.)/ha	3.96 ± 2.82b
Malathion, 1.01kg (A.I.)/ha	6.75 ± 4.10a
Tenchu 20SG, 0.103 kg (A.I.)/ha	5.83 ± 4.81ab

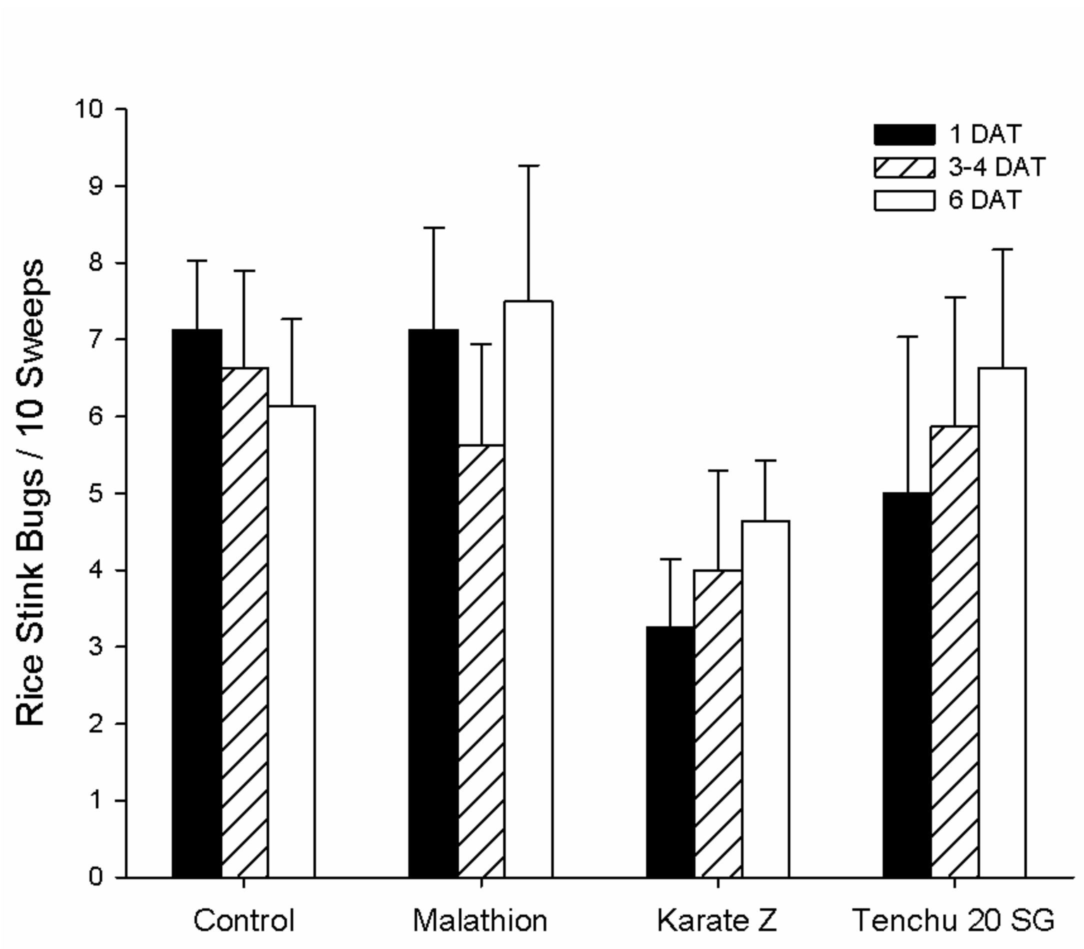

Figure 4.1 2012. Adult rice stink bugs per 10 sweeps in each treatment by sampling date.

Table 4.2 2012. Mean rice stink bug adults caught in each treatment at each sampling time.

Treatment	1 DAT	3-4 DAT	6 DAT
Untreated Control	7.13 ± 0.90	6.63 ± 1.27	6.13 ± 1.14
Karate Z, 0.045 kg (A.I.)/ha	3.25 ± 0.90	4.00 ± 1.30	4.63 ± 0.80
Malathion, 1.01kg (A.I.)/ha	7.13 ± 1.33	5.63 ± 1.31	7.50 ± 1.77
Tenchu 20SG, 0.103 kg (A.I.)/ha	5.00 ± 2.04	5.88 ± 1.67	6.63 ± 1.54

2013. No significant difference in average rice stink bug nymph densities was seen between malathion at the 0.9 lbs a.i./ ac rate and the untreated check (Table 4.3, Figure 4.2). Additionally, at the 2 HAT time point the average stink bugs per 10 sweeps were marginally higher in the lower malathion rate than in the control plots (Table 4.4, Figure 4.3). The higher rate of malathion provided control at a level comparable to Karate and Fastac, with all three treatments having significantly fewer rice stink bug nymphs than the control at the first two sampling dates (Table 4.3, Figure 4.2).

Table 4.3 2013. Rice stink bug nymphs per 10 sweeps in each treatment by sampling date.

Treatment	2 HAT	2 DAT	5 DAT
Untreated Control	6.25 ± 1.03a	5.50 ± 2.26a	2.25 ± 1.32a
Karate Z, 0.045 kg (A.I.)/ha	0.25 ± 0.25b	1.25 ± 0.95a	0.50 ± 0.50a
Malathion, 1.01kg (A.I.)/ha	7.00 ± 2.27a	2.75 ± 0.75a	1.25 ± 1.25a
Malathionhi 0.103 kg (A.I.)/ha	0.50 ± 0.29b	1.00 ± 0.41a	0.25 ± 0.25a
Fastac EC, 0.022 kg(A.I.)/ha	0.75 ± 0.48b	1.75 ± 1.75a	0.25 ± 0.25a

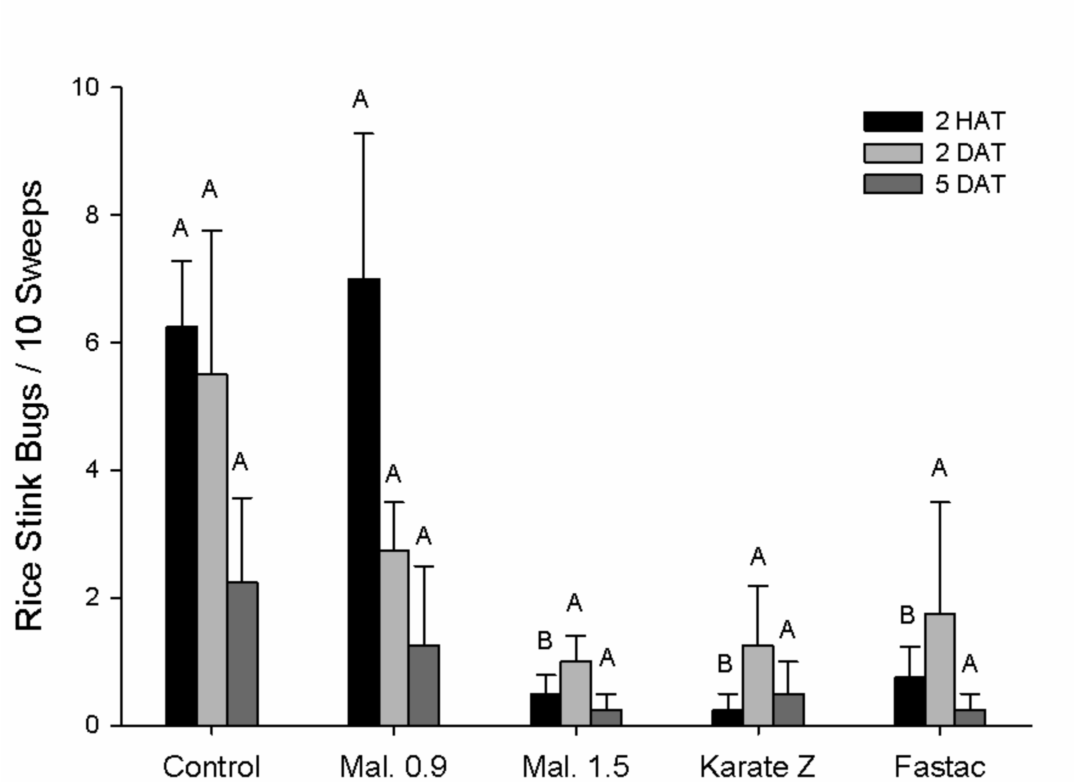

Figure 4.2 2013. Rice stink bug nymphs per 10 sweeps in each treatment by sampling date.

Table 4.4 2013. Rice stink bug adults per 10 sweeps in each treatment by sampling date.

Treatment	2 HAT	2 DAT	5 DAT
Untreated Control	9.50 ± 3.52a	8.75 ± 0.48a	3.00 ± 1.68a
Karate Z, 0.045 kg (A.I.)/ha	0.00 ± 0.00b	4.50 ± 1.76a	5.75 ± 1.65a
Malathion1, 1.01kg (A.I.)/ha	10.00 ± 4.74a	5.25 ± 0.85a	2.75 ± 0.25a
Malathionhi 0.103 kg (A.I.)/ha	6.00 ± 3.72ab	5.75 ± 3.20a	3.75 ± 0.48a
Fastac EC, 0.022 kg(A.I.)/ha	3.25 ± 2.02ab	5.50 ± 2.26a	3.50 ± 0.65a

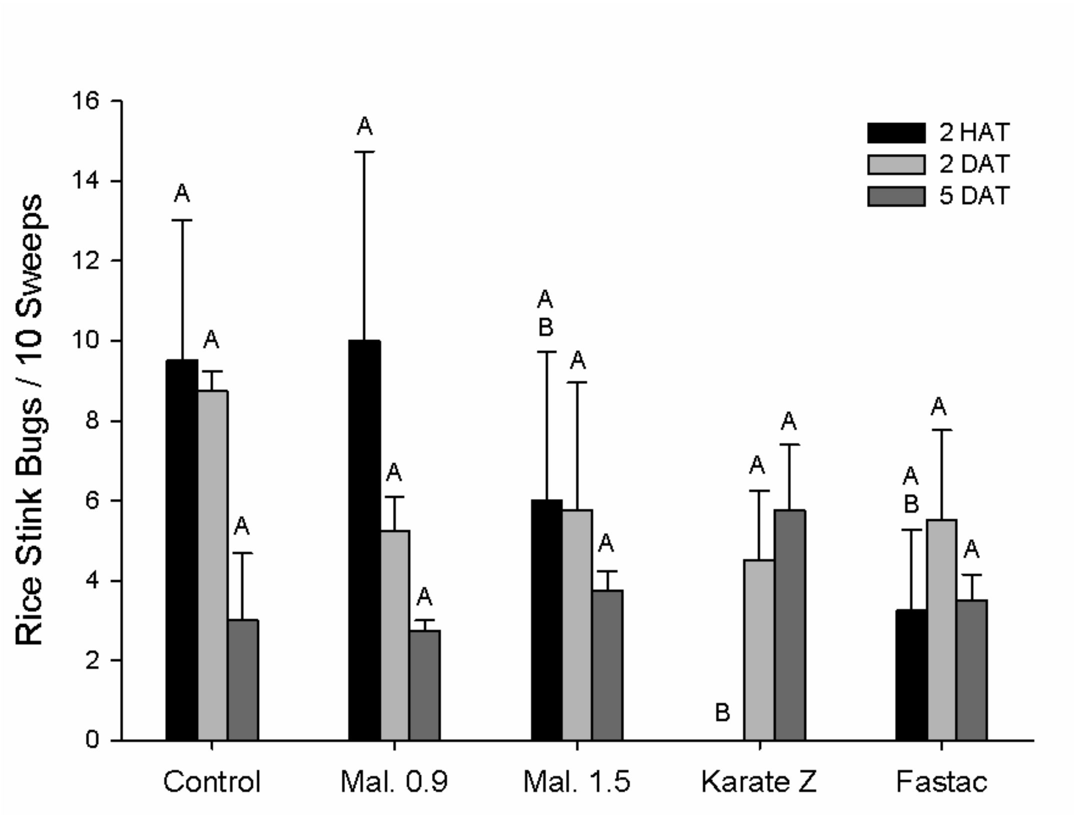

Figure 4.3 2013. Rice stink bug adults per 10 sweeps in each treatment by sampling date.

Discussion

Previous studies in Arkansas have produced similar results, suggesting that malathion at the rate of 1.01 kg A.I./ha is not effective in reducing RSB populations in rice (Johnson et. al, 2003). Laboratory tests by Way et al. in 1990 reported no residual activity of malathion beyond 24 hours at 0.56 kg (A.I.)/ha and 1.12 kg (A.I.)/ha, respectively. The combined results of these studies reveal that Malathion use over the past 50 years has resulted in diminished efficacy at the currently recommended rate. Future use of the product should be restricted or prevented altogether to prevent further resistance within rice stink bug populations and wasted resources.

The continued use of malathion is likely due to several factors: the relative cost of malathion compared to other insecticides is considerably cheaper; malathion has a pre-harvest interval of seven days compared to 14 days for ζ-cypermethrin and 21 days for λ-cyhalothrin products; and malathion has a relatively low mammalian toxicity profile. The combination of these factors have contributed to malathion remaining labeled for RSB control longer than any other product in the history of rice production in the southern United States.

Neonicotinoids have shown to reduce rice stink bug populations at the same level as pyrethroids at initial application and with equal or greater efficacy at time points beyond six DAT (Blackman et al., unpublished; Way, 1990). Organophosphates are less selective in the control of rice stink bugs in aquatic rice ecosystems. Insecticide applications impact non-target predators and parasitoids, but the reduction of bio-control agents and subsequent effect upon rice stink bug populations has not been documented. Neonicotinoids like dinotefuran are more selective because they move throughout plant tissue and act upon plant-feeding insects like rice stink bugs. Dinotefuran is also much less toxic to mammals than Karate Z or malathion (Tomizawa and Cresida 2006). When pyrethroids and neonicotinoids are rotated in a rice stink bug insect resistance management plan they should serve as adequate options for producers to lower rice stink bug densities in headed rice while also minimizing the effect on non-target insects and the environment.

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CHAPTER 5: SUMMARY OF SOUTHERN RICE PRODUCER PRACTICES FROM A MULTISTATE SURVEY (2008-2012)

Introduction

The integrated pest management (IPM) (Stern et al. 1959) practices to control insect pests of rice in the southern United States are primarily focused on containing populations of the two primary pests, rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kurschel, and rice stink bug (RSB), *Oebalus pugnax* (F.), below economic injury levels (EIL) (Helm 1955, Gifford et al. 1975, Tindall 2004). Rice production and IPM practices in Louisiana have changed dramatically over the past decade. Clearfield® technology, which allows rice plants to tolerate applications of imidazolinone type herbicides, has been widely adopted and Clearfield® varieties were planted on 61% of rice acres in Louisiana in 2013. Use of Clearfield® varieties has resulted in a movement away from the use of water seeding to manage red rice and in an increase in drill seeding. Hybrid rice adoption has also grown over the last decade. With these new innovative technologies come added initial costs to farmers, as seed costs for Clearfield® and hybrid varieties are higher than in conventional varieties.

The most important change in management practices for insect pests has been the introduction and increased use of insecticidal seed treatments for rice water weevil and other early season pests. Seed treatments provide preventive insurance to protect their investments. Increased water conservation is a welcome byproduct of the adoption of these technologies due to the fact that producers no longer have to drain fields to promote seedling rice root penetration or control newly hatched rice water weevil larvae (Webb 1914). In addition to the introduction of seed treatments, new insecticides have been introduced for rice stink bug management and older products have been phased out. Knowing how producers adopt new production practices is vital to research and program planning.

In 2008, a survey was conducted to determine the IPM practices of rice industry personnel in Louisiana and surrounding states. Questions focused on the sampling practices, insecticide use patterns, and cultural control tactics implemented by producers, consultants, and land managers when managing their rice crop. Surveys in subsequent years were modified and the target population was expanded to include personnel in southern rice producing states.

Materials and Methods

Surveys were distributed following each growing season during production meetings, through email, and via the Louisiana Rice Insects blog (http://louisianariceinsects.word press.com). In 5 years, 851 surveys were completed from five states: Louisiana (604 surveys), Texas (127 surveys), Arkansas (90 surveys), Missouri (19 surveys), and Mississippi (9 surveys). Survey respondents identified themselves as: rice farmers (62%), consultants (20%), dealers (4%), and others (15%), (e.g. county agents, researchers, manufacturer representatives, marketing managers and land owners). Louisiana farmers were the primary target of the survey, and these results show that they provided the majority of responses in the across all five years.

Respondents were asked to provide basic information about their rice farming experience, adoption of new technology, and use of information in the decision making process. The average respondent to the survey across all states was a Louisiana farmer with 31+ years of experience in rice farming. They scouted for rice stink bugs and treated once per season with a pyrethroid insecticide. However, they chose not to alternate chemistries from one year to the next. In 2008, they managed rice water weevils by draining fields, but in each subsequent year they preferred the use of seed treatments as the primary line of defense against the insects. Subsequently, their use of draining rice fields to reduce weevil larval populations decreased between 2008 and 2012. Their management practices were gleaned primarily from print publications and consultants.

Results

The majority of respondents resided in Louisiana. Within that state, most respondents identified their rice acreage as 501-1000 acres and the most frequent level of rice production experience was 21-25 years. Over 80% of farmers in Louisiana reported that they acquire information about rice IPM from consultants- the largest percentage for any category. The use of print media (76%) and extension meetings (73%) were the second and third most popular sources among Louisiana respondents.

Integrated Pest Management. Respondents were asked to note all forms of rice water weevil management used in each year of the survey (Table 5.1). Most respondents managed multiple rice fields, which tend to vary with respect to varying pest makeup and density. The IPM methods listed in Table 5.1 are primarily used to manage rice water weevils and are also effective at interrupting the life cycles of various other species of pests based on respective feeding habits, mobility, and life cycles. These combined factors explain why the sum of all categories for each year is greater than 100%. Responses from Louisiana respondents showed a large percentage of respondents using Dermacor X-100® than any other management practice after 2008. Seed treatments of Dermacor® and CruiserMaxx™ Rice compiled the greatest percentage of respondents in the last two years of the survey. Draining fields decreased from 43% in 2008 to 18% in 2012. Less than 10% of respondents said they did not use any management tactic to reduce weevil damage. The use of one practice does not exclude another. The increased trend towards seed treatment use can be explained by the fact that they were initially introduced in 2008 and producers gradually adopted as research and early adopters validated the efficacy of the products. Additional factors that likely swayed adoption of seed treatments are that they: are relatively easy to use, reduce time spent on scouting and alternative control options, are effective against minor pests, and they are safe to use in crawfish and rice rotations. The survey did not allow respondents to confirm their individual reasons for adoption. Something that was captured in the survey was that the increase in use of seed treatments coincides with a relative reduction in draining fields and use of pyrethroids, the latter being toxic to crawfish.

Table 5.1 Percentage of respondents who reported they used the listed method(s) to control or prevent rice water weevil infestation in rice.

	Method used to control rice water weevil (2008-2010)	Percentage (%) 2008, LA	Percentage (%) 2009, LA	Percentage (%) 2010, LA	Percentage (%) 2011, LA	Percentage (%) 2012, LA
Cultural control	Delayed application of permanent flood	13	25	19	15	20
	Early planting to avoid infestation	18	31	25	23	39
	Drained field	43	37	30	20	18
Pre - Plant	Dermacor® X-100 seed trtmnt	17	51	63	53	64
	CruiserMaxx™ seed trtmnt	N/A	N/A	19	26	36
Pre - Flood	Pyrethroid impregnated on fertilizer	21	27	30	10	10
	Treatment with Trebon™	9	8	3	3	0
	Foliar spray of pyrethroid	36	31	31	15	13
Post - Flood	Foliar pyrethroid spray	39	45	34	16	20
	Treatment with Trebon™	20	13	4	1	0
Nothing		6	2	1	4	0

The number of respondents that reported having rice stink bugs and rice water weevils in their fields remained relatively consistent between 2009 and 2012. Rice stink bugs were seen by 79% of respondents in 2011, the lowest year, and rose to 89% in 2012. The presence of rice water weevils was reported by 90% to 91% of respondents across all years.

Approximately 35% of farmers in Louisiana reported not spraying for rice stink bugs from 2009 to 2012. During the same period, 46% sprayed once and 16% made two pesticide applications for rice stink bugs in the state. Less than 5% had to spray more than three times.

Over the 5 year survey, 446 Louisiana respondents identified which, if any, insecticide they used to treat RSB (Figure 5.1). The majority treated their crops with the pyrethroids Karate Zeon® (51%) or Mustang Max™ (24%). The organophosphate insecticides malathion (19%) and methyl parathion (9%), were also applied by some respondents. Recent research by LSU AgCenter entomologists has shown that malathion is no longer effective at controlling rice stink bugs, after 50 years of use. Methyl parathion is no longer available for use in any crop, which leaves pyrethroids as the only option for rice stink bug control. Applying one class of insecticide repeatedly to an insect population will eventually create a resistant population of insects. During the survey period, a new insecticide, Tenchu 20SG, was tested for use in rice in Louisiana and shown to be as effective as Karate Zeon® against rice stink bugs. Use of Tenchu 20SG, a neonicotinoid, grew from 8% in 2011 to 16% in 2012 before receiving a full label in 2013, after the survey ended.

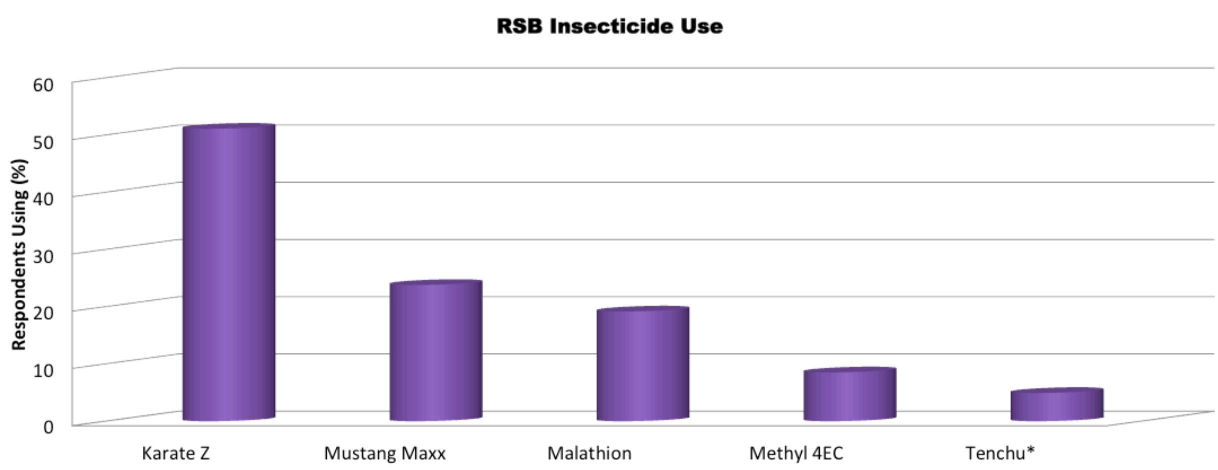

Figure 5.1 Five most popular insecticides used to manage rice stink bug populations in order of usage as reported by Louisiana respondents (2009-2012 growing seasons). The use of one insecticide does not exclude another. *Tenchu 20SG was not labeled in Louisiana until 2013. It received a Section 18 label from 2010-2012.

Among all states in 2009 through 2012, print media ranked as the most popular source of IPM information (Figure 5.2). The remaining top five sources included: consultants, meetings, extension personnel, and websites. These multi-state results differed from results from Louisiana where respondents reported using consultants more than any other choice.

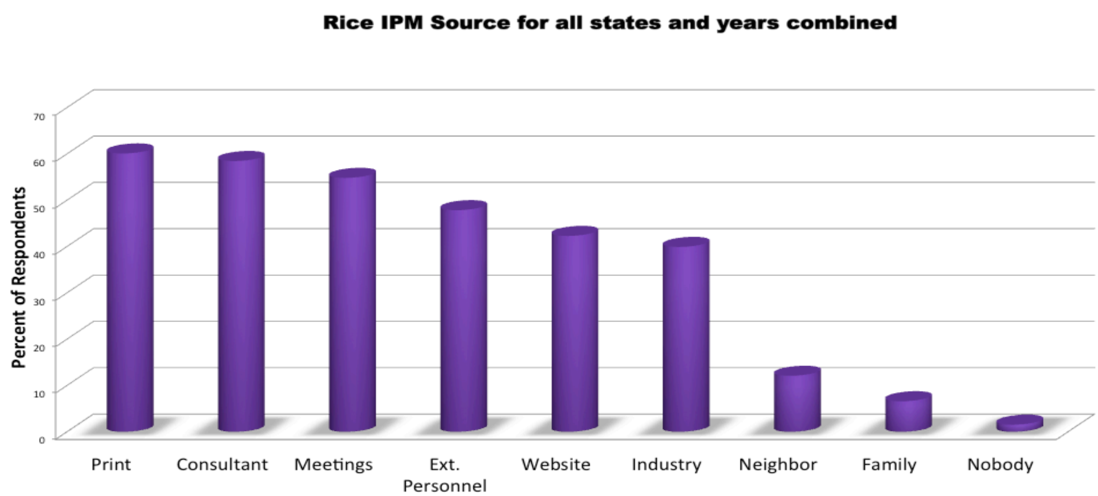

Figure 5.2 2009-2012. Percentage of respondents for each category describing where producers go for information on rice management.

Discussion

These surveys provided a valuable picture of producer practices while highlighting a need for more insecticide options in rice IPM. Repeated use of insecticides in the same class for control of a single insect population will eventually lead to insecticide resistance. Two or more insecticides used in rotation that act on different target sites in a pest population are necessary to slow onset of resistance and prolong the use of insecticides (Tabashnik 1989). Heavy reliance on

Dermacor® for rice water weevil control and pyrethroid sprays against rice stink bugs is a definite cause for concern from a resistance management standpoint. Additionally, the continued use of draining to combat rice water weevils must be reexamined to ensure that it is still effective and economically viable.

Even as more resources become available on the Internet, the use of print media and face-to-face meetings remain important to rice farmers today. This survey demonstrates the continuing need for extension agents and specialists to communicate relevant research to producers in person and through print publications. The use of Internet resources on smartphones in rural farm areas may be restricted by proximity to cellular radio towers and subsequent data signal strength. Thus, farm personnel will continue to rely on information in the form of downloadable digital and hard copy resources or personal face-to-face and telephone communication until rapidly accessible Internet sources are economically practical in rural farming areas.

The design of the survey did not allow for extensive analysis because more emphasis was placed upon asking questions in a way that promoted simplicity and efficiency to encourage participation. Possibly, future surveys can be conducted and compared to these results to provide further insight into the changing rate of adoption of rice IPM practices and how extension agents and specialists can better serve their clientele.

This survey would not have been possible without the support of numerous county extension agents and rice industry participants. The authors are grateful for their support. This survey was supported in part by the Louisiana Rice Research Board and the Southern Region Integrated Pest Management Program.

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CHAPTER 6: EVALUATION OF THE RELATIONSHIP BETWEEN RICE STINK BUG DENSITY AND DAMAGE TO LONG-GRAIN RICE

Introduction

The rice stink bug (RSB), *Oebalus pugnax* (F.), is the major late season pest of rice in the United States. The RSB is distributed in North America east of the Rocky Mountains as far north as New York and south into the Gulf Coast states (Froeschner 1988). C.V. Riley first determined that RSB was a pest of rice in 1882. Since that discovery, the RSB has consistently been considered a major pest of heading rice in the southern US (Webb 1920, Douglas 1939, Douglas and Ingram 1942, Brook 1953, Odglen and Warren 1962, Swanson and Newsom 1962, McPherson 1982, Way 1990).

Adult RSB are distinguished from other pentatomids by their smaller size, about 1 to 1.25 cm in length, light brown color, and pronated spines on the pronotum. The shield-shaped body of the RSB is the most defining characteristic of Pentatomidae. Adults live approximately 30 to 40 days, and during that time females can lay as many as 915 eggs under optimum conditions (Nilakhe 1976). About 25% of eggs laid by mated females are sterile (Nilakhe 1976), and actual field survival from egg to 5th instar nymph is approximately 37% in the absence of predators (Blackman et al. 2014). Fecundity is significantly higher when RSB are reared on rice than when reared on graminaceous weeds (Nilakhe 1976). Eggs are laid in double rows of approximately 10 to 60 on leaves, stems, and panicles of host plants and hatch in 4 to 8 days (Ingram 1927, Odglen and Warren 1962, Nilakhe 1976). Nymphs complete five instars in 15 to 28 days (Douglas 1939, Douglas and Ingram 1942).

Rice stink bug feeding on both rice florets and developing rice kernels from the R4 to R8 stages (Counce et al. 2000) of panicle development causes several distinctive types of grain damage (Table 6.1), which may result in significant economic loss for producers. To extract nutrients from the developing grains of host plants, rice stink bugs insert their piercing-sucking mouthparts into the seed and inject salivary enzymes that allow grain contents to be dissolved and extracted through a stylet sheath (Bowling 1979). Injured florets result in blank rice grains, which are removed during harvest and realized as lower rough rice yield. RSB feeding after anthesis can result in kernel damage manifested as discolored kernels, chalky kernels, broken kernels, and reduced kernel weight (Douglas & Ingram 1942). The discolored kernels, known as pecky rice, are the combined result of direct feeding damage and infection by pathogenic microorganisms transmitted to the developing grain during rice stink bug feeding during the milk and soft dough stages of panicle development (Douglas & Tullis 1950, Espino & Way 2006). Pecky rice is distinguished by characteristic bulls-eye lesions emanating from a small pin hole at the point of stylet insertion (Figure 6.1). Pathogens related to peck caused by RSB are: *Curvularia lunata, Bipolaris oryzae, Cercospora oryzae, Trichonis caudata, Fusarium oxysporum, Alternaria* spp., and *Nematospora coryli* (Daugherty & Foster 1966, Marchetti 1984, Hollay et. al. 1987).

Table 6.1 Types of damage resulting from feeding by rice stink bugs at different stages of panicle development (Bowling 1979, Espino et al. 2006, Blackman et al. unpublished).

Type of damage	Panicle development stage susceptible to damage	Resulting economic loss
Blank grains[1]	Anthesis	Reduced rough rice mass
Broken kernels[2]	Milk & Soft Dough	USDA grade reduction
Chalky kernels[3]	Soft Dough	USDA grade reduction, reduced mass during milling
Pecky kernels	Milk, Soft Dough, Hard Dough	USDA grade reduction, reduced mass during milling

[1]Rough rice grain devoid of kernel. [2]Kernels of rice which are less than three-fourths of whole kernels. [3]Whole or broken kernels of rice which are one-half or more chalky (opaque). (USDA-FGIS 2009)

Reductions in mass of rough rice and milled rice are of major economic concern when rice stink bugs feed on rice. Rough rice consists of unprocessed grains contained in hulls, while milled rice is the final product in a system of processing that removes the hull, germ, and bran layers. Milled rice yield (MRY) is a percentage of initial rough rice weight (Siebenmorgen 2014).

$$\text{MRY}= \frac{\text{Milled rice mass}}{\text{Rough rice mass}} \text{ x } 100$$

Both whole and broken white rice grains make up milled rice. USDA grades are assessed using samples of dehulled brown rice and milled white rice. Visual damage to rice grains (chalk, peck and broken kernels) results in reduced USDA grade and reduced purchased price. Chalky and pecky kernels may have reduced physical integrity that can result in breakage during milling.

There have been various attempts to quantify damage (economic losses) from RSB feeding in recent decades. Early estimates suggested rough rice yield loss due to rice stink bugs could account for 25% of total yield loss in a field (Douglas & Ingram 1942). Fryar, et al. (1986), estimated that the economic impact of RSB in 1983/1984 season in Arkansas was $0.375 a hundredweight for each percentage point of peck present. One percentage point of peck with rice production at 4,500 pounds per acre resulted in a $19.50 loss per acre that season (Fryar 1986). Similar studies in Texas estimated RSB caused between $5.91 and $23.34 per acre in damage from 1981-1984 (Brorsen 1988). In 2000 and 2001, Arkansas rice producers suffered an increase in the number of discolored kernels damaged by RSB. The resulting damage led to decreases up to $0.25 per bushel (Johnson et al. 2006).

Historical Threshold Studies. Attempts to characterize the relationship between rice stink bug density and damage have been recorded in almost every decade since 1950 (Table 6.2). Experiments have been carried out in one or a combination of the following ways: by confining a known density of stink bugs to an individual panicle using a mesh cage during a period of time when panicles are susceptible to rice stink bug feeding and collecting yield and damage data from grain samples; confining a known density of stink bugs to a group of plants using a larger cage during a susceptible period and collecting yield and damage data from grain samples; or by regularly monitoring plants throughout the period of panicle development and inspecting grains from those plants for damage. The area of confinement in cage studies can greatly affect the focus and outcome of the experiment. Confining insects to an individual panicle allows for rapid assessment of insect mortality and replacement of dead insects in the midst of an experiment. Caging insects on whole rice plants differs from the panicle method in that whole plants are confined in cages and insects are extremely difficult to locate when insects are not feeding or resting on panicles. Ensuring that the area covered by a cage is free of undesired RSB or predators at any life stage with absolute confidence is difficult. However, large cage studies are closer imitations of field conditions than panicle cages, and their use has dominated the density-damage experiments over the years.

Douglas and Tullis (1950). Rice stink bug adults and fourth and fifth instar nymphs were caged (103.23 cm^2) together in densities of 2 to 14 insects on 50 plants (Blue Rose cv.). Insects were confined beginning at the boot stage until grain maturity, approximately 30 days. Rough rice and brown rice was analyzed to determine percent blank grains and discoloration, including pecky rice. Peck and discoloration was relatively greater in cages with higher infestation levels. Peck ranged from 5% in cages infested with a pair of RSB adults to 76% in cages with seven adult pairs. Rough rice mass was reduced by 18% compared to controls. Nymphs in the fourth and fifth instars were seen to cause peck, but the percent peck was considered to be highly variable. Blank grains ranged from 6% in untreated to 77% in infested cages. The authors also noted that high densities of rice stink bugs caused chalkiness, which resulted in powdery samples after milling in a Smith shelling device.

Helm (1954). Milling samples provided by rice driers in Louisiana, Texas, and Arkansas were analyzed to determine the relationship between planting date and percent pecky rice. Helm concluded that rice in Arkansas was damaged less than rice in Louisiana and Texas. Helm concluded that samples from fields that had matured to hard dough before July 20 or had not reached the milk stage by September 20 contained less pecky rice than those fields that were in the milk to soft dough stages between those dates.

Helm (1955). Rice stink bugs were sampled in fields of Zenith cv. rice and insecticide applications were made. Post-treatment counts were taken and percent pecky rice was determined for harvested samples. Helm concluded that the tested insecticides reduced RSB populations to levels lower than 5 RSB per 10 sweeps. He concluded that this threshold was appropriate by comparing economic data for rice prices and expected yield in 1954.

Odglen (1960). Adult and nymph rice stink bugs were caged on rice to investigate the relationship of rice stink bug density to rice grain damage relationship during one season. Cages (0.093 m^2) were infested when rice was at panicle emergence, milk, and soft dough stages.   The author did not outline the seeding rate, plant count, or panicle density for cages. Thus, insect to panicle ratio could not be calculated as in other studies. Insects were caged until harvest except in the final treatment when cages were removed after one week. No significant differences were seen for yield or grade among controls and caged densities of 20, 40, and 80 adult and nymph rice stink bugs. Odglen concluded that rice stink bugs at levels similar to those tested did not warrant insecticide applications.

Swanson and Newsom (1962). Cages containing 1,000 to 2,000 panicles were infested with densities of 0, 20, 100, or 500 adult and 5th instar nymphs just prior to panicle exertion. Brown rice was analyzed for RSB damage for all samples except the 500 insect density, which was analyzed after milling. Rice samples from plots with 500 insects had drastically increased kernel damage, yield reduction of 50%, and negative impact on milling, grade, and seed viability. The authors concluded that populations of 7 to 8 insects per 1,000 panicles were economically important. Mortality of RSB in cages was reportedly 50%.

Bowling (1963). The author performed cage studies in two separate studies with varying results. Study one was carried out over two years and resulted in no significant differences for RSB per cage (0.093 m^2) and yield or peck. Densities of RSB were not reported for test one. The report focused on the second study, which used larger cages (7.43 m^2 and 5.57 m^2) infested with 0.093, 0.186, and 0.372 RSB per m^2 (1, 2, and 4 insects per ft^2) when panicles began to emerge. Rough rice yields were not significantly different in three of four tests, but in the fourth test a significant difference was seen for rough rice yield between the highest density and the control. Significant differences between untreated check and highest RSB density in percent peck were observed in all but one test.

Bowling & Thomas (1979). Individual panicle cages were used to contain rice stink bug adults and nymphs to compare salivary feeding sheaths among life stages and sexes (Bowling 1979). Nymphs were seen to feed as often as adults, and females fed more than males. Bowling suggested the use of stylet sheaths to create more precise rice stink bug thresholds.

Harper et al. (1988). Rice plots were sampled via sweep net and densities of rice stink bug were recorded to determine a relationship between seasonal pest levels and the percent pecky rice in the same plots. This study was the first to look at the rice stink bug density-damage relationship using semi-dwarf varieties. The study resulted in the adoption of the dynamic rice stink bug threshold, similar to the one currently implemented in Texas, which incorporates projected purchase price of harvested rice, expected yield, and cost of application into the treatment decision.

Espino and Way (2007). Greenhouse and field studies were carried out to investigate the relationship of timing of feeding by RSB adults and nymphs and subsequent types of damage. Cages (0.1590 m^2) contained 20 (2005) or 12 (2006) plants infested by either 12 adults or 12 third to fifth instar nymphs. Methods were repeated in the greenhouse in 2005, and both the greenhouse and field plots in 2006. Findings showed that rough rice yield was not affected by RSB feeding. Percent peck was significantly higher in cages in which adults fed at the milk stage than adults or nymphs feeding at any other stage. The soft dough stage was also considered a highly susceptible stage for pecky rice development. The authors suggested that revised thresholds include rice stink bug nymphs.

Table 6.2 Summary of previous research investigating relationship of RSB density and damage in rice.

Year	Author	Threshold	Method
1950	Douglas & Tullis	14 RSB per 50 Plants	Cage
1954	Helm	none	Milling samples
1955	Helm	5 RSB / 10 Sweeps	
1960	Odglen	None significant	Cages
1962	Swanson & Newsom	7 / 1000 panicles	Cages
1963	Bowling	none	Cages

1979	Bowling & Thomas	10/10 sweeps	Panicle cages
1980	Bowling	5/10 sweeps	Petri dish, Panicle Cage
1988	Harper et al.	Dynamic threshold based upon expected yield and treatment costs	Sweep net
2007	Espino & Way	Revised thresholds of Harper et al.	Cages

As the findings of these and other unpublished density-damage studies were released, economic thresholds were proposed for RSB management. Swanson and Newsom attributed a threshold of two RSB per 10 sweeps to Helm in 1954, although the referenced paper has no direct mention of the threshold. Bowling and Thomas mentioned an RSB threshold of 10 RSB per 10 sweeps in 1979, and in 1980, Bowling recommended treating when an average of 5 RSB per 10 sweeps are present in a field during panicle development (Bowling 1980). Neither Bowling reference applied the given thresholds to a specific period of panicle development. In 1981 the Texas Agricultural Extension Service officially recommended the treatment threshold of 5 RSB per 10 sweeps during the first two weeks of heading and 10 RSB per 10 sweeps in the second two weeks of heading and the University of Arkansas Cooperative Extension Service adopted them soon after (McIlveen, Drees, and Bowling 1981). Thresholds advised producers to sample fields with a 38 cm sweep net beginning at 75% panicle emergence. Louisiana has consistently maintained a more sensitive threshold of three rice stink bugs per 10 sweeps in the first two weeks of panicle development since the early 1980's. This difference in the Louisiana threshold may take into account the work done by Bowling in Texas and the more sensitive recommendation attributed to Helm whose experiments were carried out in Louisiana.

Recently, threshold recommendations have been adjusted in Texas and Mississippi (Allen et al. 2014, Way et al. 2014). In Texas, early thresholds have been adjusted to levels ranging from 8 RSB in 10 sweeps during heading to 94 RSB in 10 sweeps during the hard dough stage (Way et al. 2014). These levels vary according to panicle development stage and projected yield.

The Texas thresholds were based primarily on the Espino et al. (2007) study. Mississippi entomologists have altered the timing of thresholds from the weeks of heading to the actual panicle development stages to account for variations among varieties and to ensure insects are monitored more effectively at the most sensitive stages for damage to occur. Mississippi recommendations are based upon unpublished work done by Arwuni et al. Unlike thresholds recently released by Texas, Mississippi will be recommending thresholds as low or lower than the 3 RSB per 10 sweeps suggested in Louisiana (Jeff Gore, MSU, personal communication).

Ultimately, the goal of economic thresholds for control of RSB is to prevent damage from occurring that reduces the economic value of the crop (Stern 1959) while at the same time reducing unnecessary insecticide applications. Developing useful economic thresholds requires not only an understanding of the relationship between insect density and damage, but also knowing how that relationship can be applied to practical and effective sampling measures already adopted by producers. The previous studies have not agreed upon the types of damage that can be attributed to RSB feeding and how damage changes with RSB density. Likewise, these studies did not address the relationship between treated field or cage area and the recommended sampling methods and area used in implementation of thresholds. However, separate studies have sought to determine the utility of sweep net sampling for rice stink bugs and to develop more desirable methods of sampling (Bowling 1969, Cherry and Deren 2000, Rashid et al. 2006, Espino et al. 2008). Bowling (1969) compared sweep net counts of RSB to visual observation. Cherry and Deren (2000) saw no difference in sampling results and time of day, air temperature, or wind speed, but Rashid et al. (2006) concluded that sampling in the hottest part of the day was less effective for determining population density. Espino et al. (2008)

concluded from their research that the sweep stick method is a more efficient alternative to the sweep net, and they developed a sequential sampling plan for both sampling methods.

Experiments were conducted in 2010-2012 to investigate the efficiency of RSB sweep net sampling and the RSB density – rice damage relationship during the first two weeks of panicle development to determine if thresholds in Louisiana need to be updated. Sweep net efficiency was estimated by releasing marked adult RSB in small plots and sweeping plots to determine the recapture rate. Results were compared using regression analysis. The relationship between rice stink bug density and damage was investigated using cages in which varying densities of RSB were released for 14 days. Numbers of RSB released were calibrated to approximately 0, 1x, 2x, 5x, 10x, and 20x current thresholds in Louisiana. Plots were harvested by hand and assessed for rough rice weight, blank grains and percent peck. Means were compared using ANOVA in SAS.

Materials and Methods

Experiments were conducted at the Louisiana State University Agricultural Center Rice Research Station (RRS) in Crowley, LA. The soil type at this location was a silt loam (fine, montmoillonitic, thermic, Typic Albaqualf). Plots of rice, 1.5 m x 6.1 m, were drill-seeded at 67.25 kg/ha and managed following LSU AgCenter recommendations for fertilization and control of weeds and pathogens (Blanche et al. 2009).

When needed for experiments, rice stink bugs were collected via 38 cm sweep-nets in fields of rice and weedy grasses at the RRS and placed in a paper bag or screened aluminum collapsible cage (Bioquip, Rancho Dominguez, CA) prior to transport to the laboratory. Immediately upon arrival at the lab, bags and cages containing RSB were held at approximately 4.5°C (40°F) to immobilize insects so they could be observed for injury and to prevent escape during handling and transfer to 1 oz diet cups. After approximately 10 minutes of refrigeration, insects were returned to room temperature, and healthy adults were transferred to diet cups. Cups were filled with 1, 2, or 5 RSB, labeled accordingly and capped.

Mark-Recapture Study. To determine the efficiency at which sweep net sampling captures RSB in rice, mark-recapture experiments were performed in 2010, 2011, and 2012. Uniform small plots (1.5 m x 6.1 m) of untreated rice in the heading to hard dough stage of panicle development were selected to serve as release plots for release and recapture of marked insects. Rice variety and seeding rate varied among plots and years, but the majority of plots were of the Cocodrie variety planted at rates ranging from 67 to 100 kg/ha.

Rice stink bugs were observed as they regained mobility from being refrigerated, and insects displaying typical behavior were marked with liquid correction fluid. Markings were restricted to the pronotum so that flight was not inhibited. After fluid dried, insects were placed in diet cups and transported to the field. Insects were gently released from diet cups on to rice panicles by hand evenly throughout plots at densities ranging from 3 to 22 adults per plot. Insects that flew off or that were observed dropping into the water prior to sweeping were not counted in infested totals. Insects were allowed to settle in plots for approximately one minute before sweeping was initiated. Each plot was sampled with 10 consecutive sweeps, and the total number of marked stink bugs captured in plots was recorded. Sweeps covered the entire width of the plot as the practitioner walked the length of the plot along the border. The entire mark-recapture process was repeated in 50 plots between 2009 and 2012.

The relationship between the number of rice stink bugs released and the number recaptured was determined using regression analysis in PROC REG of SAS (SAS Institute 2011).

Cage Study. Cages were placed in heading rice plots (Cocodrie cv) and infested with varying densities of RSB adults assigned to plots in a randomized block design. Adult insects were confined in cages for 11 (2010) or 14 (2011-2012) days. After cage removal, plots were treated with insecticide to prevent further infestation and feeding. Harvested rice was weighed and evaluated for blank grains and percent peck to determine the relationship between adult stink bug density and damage.

Cages measured 0.94m long by 0.66m wide and stood 1.65 m tall. The total area encompassed by cages, 0.62 m^2, was approximately 70% of the area of rice encompassed in one 180-degree sweep with a 38 cm sweep net. Densities of stink bugs were determined using preliminary data from the mark-recapture study, which showed that sweep nets capture approximately 20% of RSB adults present in rice fields. Infestation levels equated to 0, 1x, 2x, 5x, 10x, and 20x current thresholds (Table 6.3). Cage frames were constructed of 1.91 cm diameter pvc pipe. Fabric enclosure was constructed of mesh netting (6x6, Hummert International, Earth City, MO), which was sewn to fit tightly over the outside of cage frames and held in place using plastic zip ties. Cotton fabric sleeves (30 cm diameter) were sewn onto sides of cages to allow access for infestation with stink bugs and removal of predaceous insects and frogs. Cages were held in plots by securing them with bailing wire and braided fishing line to metal t-posts, which were driven into the ground approximately 60 cm.

Table 6.3 Calculation of densities of RSB adults in cages using relationship of cage size and RSB infestation density to current Louisiana thresholds (3 RSB per 10 sweeps) and sweep net sampling efficiency.

Cage Infestation levels (relative to threshold)	Desired no. of RSB per sweep (y)	Actual no. of RSB	No. of RSB per cage
1x	0.3	1.05	1
2x	0.6	2.10	2
5x	1.5	5.25	5
10x	3.0	10.50	10
20x	6.0	21.00	20

Column two (y) represents the number of RSB in one sweep necessary to meet column one values. Column three is equal to [(x*0.7)/0.20] where 0.7 is the proportion of a sweep encompassed by the area of the cage, and 0.2 is the sweep net efficiency (proportion of insects present in an area sampled by sweep netting). Column four is the resulting number of insects actually used to infest cages.

The rice surrounding the cages was cut with a sickle after cages were secured in plots to prevent later confusion of caged and uncaged rice after cages were removed. A pyrethroid insecticide (Karate Zeon®, Syngenta Crop Protection, Greensboro, NC) was applied to plots at the labeled rate by backpack sprayer immediately after cage removal to prevent further feeding and infestation. Insecticide treatments continued twice per week until rice had developed beyond the hard dough stage, R8.

Rice plots were harvested at grain maturity, dried, and stored in paper bags in the lab until processing. All panicles from each plot were counted and hand threshed to ensure blank grains could be analyzed. All material resulting from threshing (blank and filled grains) was weighed, and this weight was recorded as rough rice weight. Blank rice grains and hulls were separated from filled grains in rough rice using a custom-made device consisting of a combination of screens and funnels. A No. 35 USA Standard Testing Sieve (Sargent Welch Scientific Company) served as the base in which the rice sample was placed. The bottom portion of a 17 cm diameter 3.785 L cardboard container (Neptune Paper Products Newark, NJ) was removed to create a tube to direct airflow. A trap was created to catch blank grains and hulls as they were blown over the top of the cardboard container. To create the trap, a 22.22 x 19.05 x 17.78 cm plastic funnel (Rhino Gear) was trimmed to 3 cm high with a bottom opening of 17 cm and an upper opening of 19.5 cm. The funnel fit over the outside of the cardboard container and created an air tight seal between the outer edge of the sieve and the container. The funnel was joined to the container with hot glue so that blank grains falling over the side of the container would be caught in the upturned funnel. A three speed blower fan (Air King Model 9550, West Chester, PA) provided enough air flow to force blank grains and hulls above the top of the container without also allowing filled grains to escape. The funnel and container were set inside the sieve and a 25.5 x 19 x 22 cm, 6 L clear plastic bucket (Prolon, Port Gibson, MS) was placed upside down so that the upper lip of the bucket rested on the sieve, thus creating a seal to prevent rice hulls and blank grains from escaping. The bottom of the bucket was cut off and replaced with a cloth screen held in place using a rubber seal with an inner diameter of 18 cm (Waring Commercial Blender, East Lansing, NJ). Samples of threshed rice, approximately 30 g, were placed on the sieve inside the container and the bucket was placed over the sieve. The sieve was then placed approximately 10 cm from the fan and the fan was turned up to the highest speed. After blank hulls were no longer visible in the sieve, the fan was turned off and the separated blanks and full grains were placed in two piles to be inspected and separate blanks that remained in the sieve. The process was repeated until the harvested grain from each plot was separated. Grain was then weighed to determine blank and full rice for each plot.

Hulls were then removed from rice kernels using a McGill Sheller (McGill Inc., Houston, TX) at the RRS. A 50 gram subsample of dehulled brown rice from each harvested cage plot was inspected for peck with the aid of a 150 watt high intensity microscope light. Methods for grading peck damage were adapted from the United States Department of Agriculture Food and

Grain Inspection Service (USDA-FGIS) standards (2009). Rice grains were considered pecky if they exhibited the O-type of stigmonose damage characterized by Douglas and Tullis (1950). Broken grains were more difficult to evaluate for peck because breaks typically occurred at the site of the damage. In the shelling process, the damaged feeding site did not remain intact, and portions of the pecky area were lost. Thus, typical 'bulls-eye' damage was indiscernible when samples broke during processing. Broken kernel portions were considered to be pecky if discolored areas of broken kernels appeared consistent with larger lesions (Figure 6.1). A 50 gram sample of dehulled rice from each cage was analyzed using these definitions for pecky rice. Percent pecky rice was calculated by doubling the total weight of whole kernels and partial kernels that contained traits of pecky lesions in 50 grams.

Figure 6.1 Examples of rice kernels classified as pecky from 2010-2012 cage studies.

Measures of damage included rough rice weight per panicle, percent blanks, percent peck in brown rice, and percent brown rice recovered after shelling. Yield was calculated by dividing weight of rough rice per cage by total panicles per cage. Total grams of pecky rice in a 50 g sample for each cage was multiplied by two to obtain percent peck. The percentage of blank grains was determined by dividing total weight of blanks per cage by total rough rice per cage and multiplying by 100. After blanks were removed, a 100 gram sample of the resulting rough rice for each cage was dehulled. The dehulled weight of the resulting brown rice weight was considered percent brown rice recovered.

2010. In 2010, three separate experiments were initiated on June 23rd, July 7th, and July 27th. Each experiment included five densities of RSB adults (0, 1, 2, 5, and 10 adults per cage), with one cage for each density. Each cage was placed in a plot on the day experiments were infested. Plots were gently swept prior to cage placement to remove rice stink bugs, predaceous insects, or frogs. Cages were removed after 14 days, and plots were treated with insecticide.

2011 and 2012. Tests were expanded in 2011 to include an extra set of cages for each infestation date. Cages were infested on four dates in 2011 and one date in 2012. RSB densities were modified to 0, 2, 5, 10, and 20 insects per cage. Insects were confined in cages for 11 days in 2011 and 2012 tests.

Data Analysis

2010. Percent peck among all RSB cage densities was subjected to a one-way ANOVA using PROC MIXED in SAS and the relationship between the variables was compared in a regression analysis using PROC REG.

2011 and 2012. Data from both years were combined for analysis. Rough rice weight, percent peck, percent blanks, and percent brown rice recovered were compared among all RSB cage densities by one-way ANOVA using PROC MIXED in SAS. Means were separated using Tukey's LSD. Satterthwaite's method was used to estimate degrees of freedom for missing variables.

Results

Mark-Recapture Experiment. The number of insects recaptured in the experiments ranged from 0 to 6 with a mean of 2.35 ± 0.26 (Table 6.4). A significant positive relationship was observed between total RSB released and RSB recaptured (Table 6.5). The linear model, recaptured RSB= (marked RSB released)*(0.242) + (-0.541), was found to be significant (P<.001, R^2=0.445). This result suggests that the model is a significant indicator of recapture rate and explains approximately 45% of the variation in the data (Figure 6.2).

Table 6.4 Descriptive statistics for Mark-Recapture Study.

Variable	N	Mean ± SE	Std Dev	Min	Max
Released	50	12.00 ± 0.72	5.10	3	20
Recaptured	50	2.36 ± 0.26	1.85	0	6

Table 6.5 Statistical relationship between rice stink bugs released and recaptured.

Model	n	Slope ± SE	F	P	R^2
RSB Recaptured	50	0.242 ± 0.5079	38.41	<.0001	0.4445

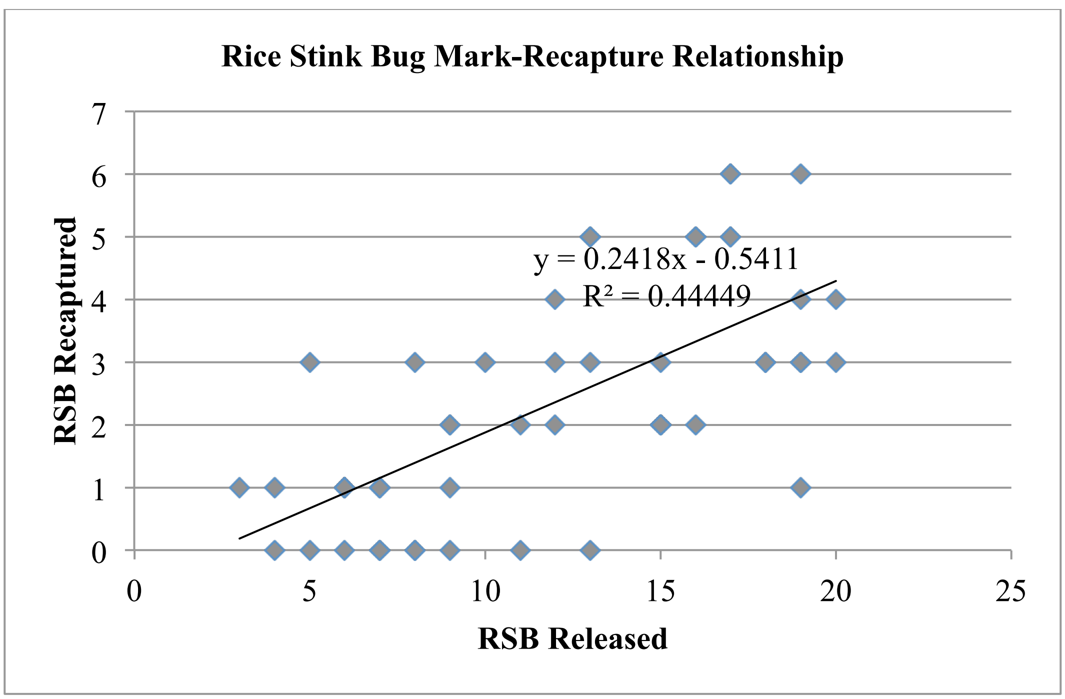

Figure 6.2 Raw data from 50 replicates of the mark-recapture experiment. RSB released are plotted on the x-axis and RSB captured are plotted on the y-axis.

Cage Studies. RSB density did not have a significant impact on percent pecky rice in 2010 ($F_{4,3.85}$ =1.15; P=0.4517) or 2011-2012 ($F_{4,43.3}$ =0.37; P=0.8291) samples. Likewise, stink bug density had no significant impact on rough rice yield ($F_{4,42.1}$ =0.44; P=0.7808), percent blanks ($F_{4,44.1}$ =1.50; P=0.2196), or percent brown rice recovered ($F_{4,37.9}$ =0.47; P=0.7587) in 2011-2012. Regression analysis showed that R^2<0.03 for RSB density and percent peck (Figure 6.3), rough rice yield (Figure 6.4), percent blanks (Figure 6.5), and percent brown rice recovered (Figure 6.6) in all respective years.

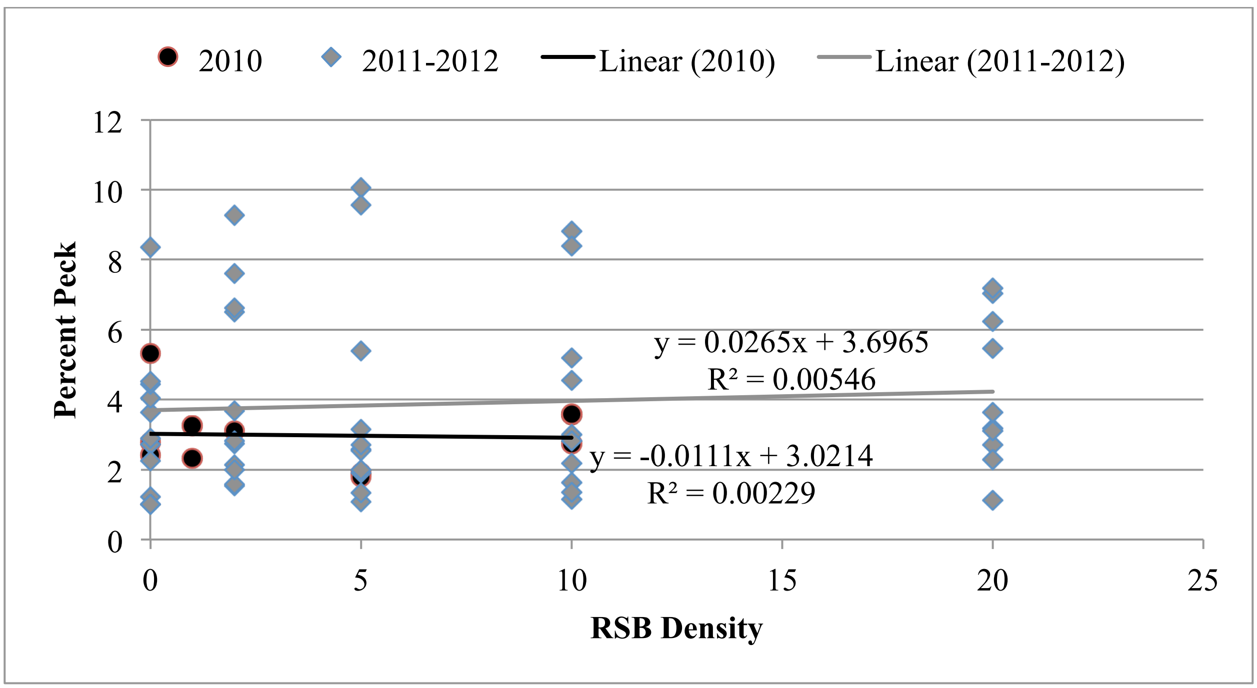

Figure 6.3 Raw data from 2010 (black circle) and 2011-2012 (gray diamond) plotted with RSB density on x-axis and percent peck on the y-axis.

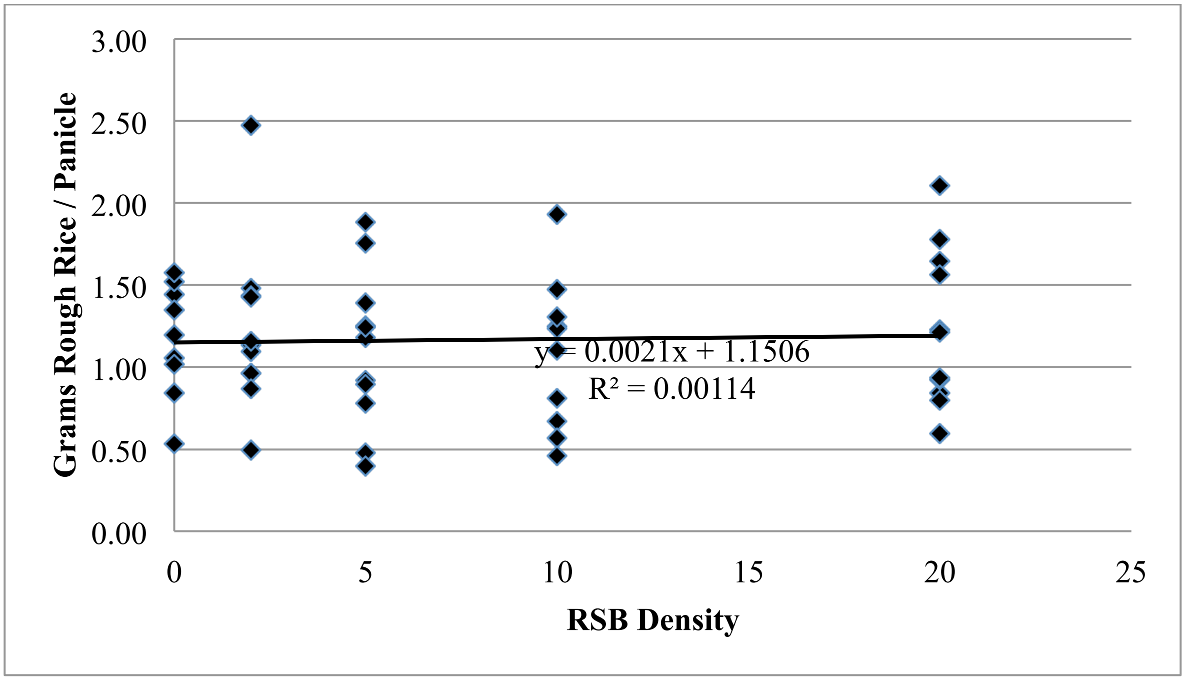

Figure 6.4 Raw data from 2011-2012 plotted with RSB density on x-axis and rough rice yield per panicle on the y-axis.

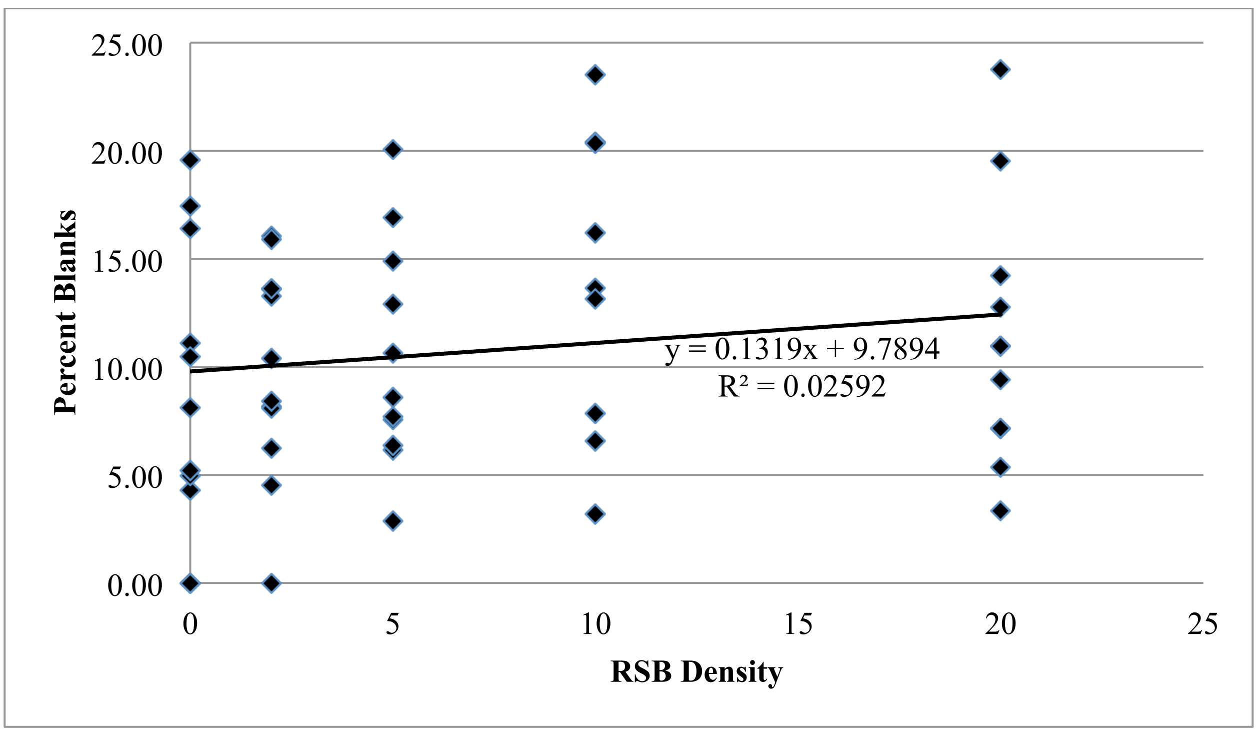

Figure 6.5 Raw data from 2011-2012 plotted with RSB density on x-axis and percent blanks on the y-axis.

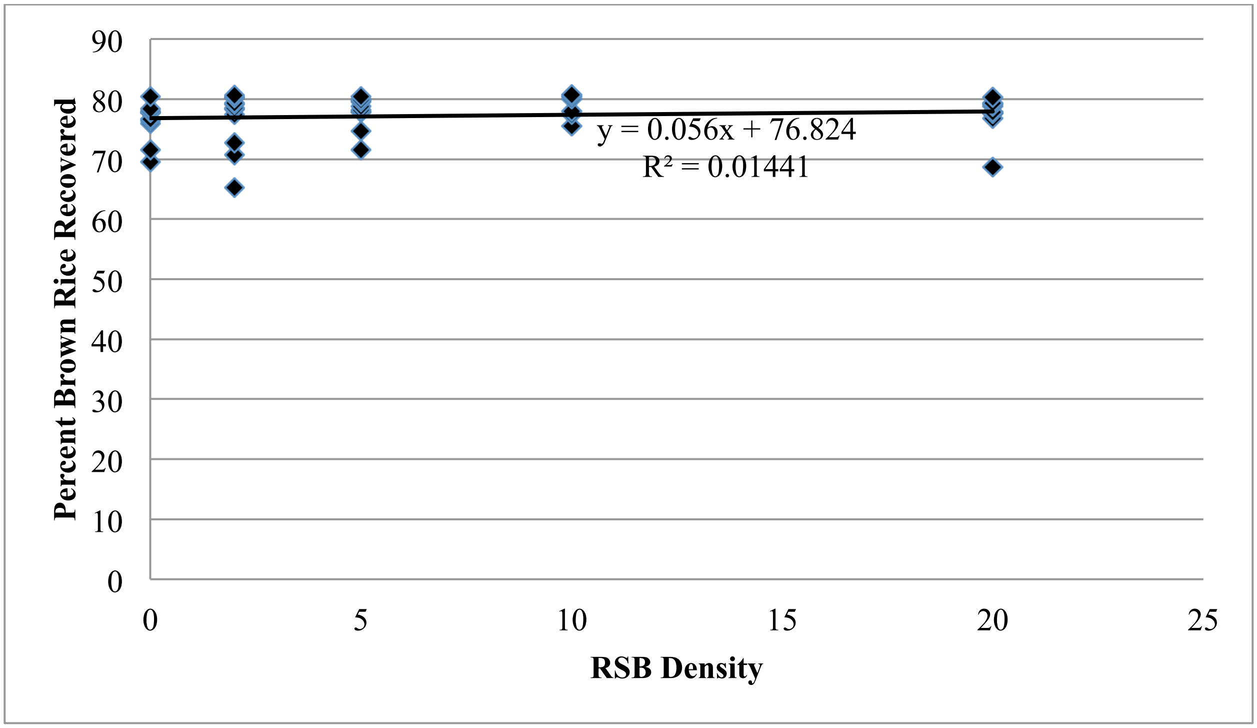

Figure 6.6 Raw data from 2011-2012 plotted with RSB density on x-axis and percent brown rice recovered on the y-axis.

Discussion

Current recommendations for sampling rice stink bugs in Texas include the use of a sweep net, sweep stick, or binoculars for visual counts, but cooperative extension service recommendations in Arkansas, Louisiana, Mississippi, and Missouri are based solely on the use of a sweep net (Allen et al. 2014, Atwell 2013, Lorenz and Hardke 2014, Stout 2014, Way et al. 2014). Bowling developed a model to describe the relationship between RSB observed in a field with the naked eye and the number sampled in 10 sweeps with a sweep net: y=12.3 + 1.66x where y=observed insects and x= RSB in 10 sweeps. Several data points in the x variable contained more insects than were actually observed in the field, which suggests that sweep nets are not as efficient as his results suggest.

The results of the 2010-2012 mark-recapture study suggested that sweep net efficiency is between 19-21% when field populations are near the 3 RSB per 10 sweeps threshold. The model (Figure 6.2) predicts that if stink bugs sampled are at the threshold level (3 bugs per 10 sweeps), then there are actually 15 insects in the area swept (i.e., 12 of 15 stink bugs present in the swept area are not captured with the net). Foster & Cherry (1986) determined that RSB distribution within a field is aggregated, and sampling an area of a field with 100 sweeps was sufficient to predict the population of the entire field. Current sampling recommendations in Louisiana suggest sweeping 10 times throughout fields at 10 locations. A better understanding of total insects within a sampled field can be developed by utilizing the efficiency rate from the mark-recapture experiment. These data would be useful for future cage studies when thresholds are investigated in relation to sweep net sampling.

Historically, RSB feeding has been thought to be responsible for blank grains, broken grains, and peck. However, not all previous cage studies investigating RSB density and rice damage have found significant positive relationships (Odglen 1960, Bowling 1963). In our experiments, no significant relationships among RSB density and damage were observed. This study does not discount previous studies that concluded such a relationship does exist, but our results do show that not all cage study methods are effective for estimating the RSB density to damage relationship in rice. The results of cage studies may be affected by variations in: cage size, RSB density, duration of RSB feeding, RSB mortality, damage before and after controlled feeding, and environmental conditions. Environmental factors directly affect RSB behavior (Nilakhe 1976, Rashid et al. 2006, Espino and Way 2007) and may alter insect feeding and mortality.

Initially, the cage study infestation period was set for 11 days to provide RSB time to feed in both the flowering and milk stages of panicle development. Days of infestation were increased in 2011 to allow insects to feed for the duration of the second week of panicle development in which RSB feeding is associated with the highest yield loss and peck damage (Espino and Way 2007). Likewise, the 14 day feeding time coincides with the lowest current ET for RSB. The lack of significance among treatment densities for pecky rice damage during the 2010 experiment suggest that feeding at levels 20x the current recommended thresholds are not significant or that peck damage occurs beyond the 11 day point of panicle development. Similar results in experiments in 2011 and 2012 suggest that pecky rice is not significant unless feeding occurs at some point beyond 14 days after panicle heading begins. Alternatively, high control peck in these experiments suggest that attempts to exclude insects prior to infestation by installing cages prior to heading and to prevent feeding post-infestation were not successful in all infestation dates. Previous studies experienced higher than expected peck in controls as well and attributed the cause to other insects (Odglen 1960, Bowling 1963). Percent blanks and percent brown rice recovered were hypothesized to be positively correlated with RSB density, but our experiments failed to find significance between these variables. Blank grains and decreased brown rice recovery are known to be caused by multiple factors including disease (Siebenmorgen et al. 2014). Panicle cage tests have been used to determine the association between RSB feeding time and subsequent type of rice damage. Our tests show that these results are not as consistent outside the greenhouse setting.

Rice stink bug mortality was an issue in several previous studies, and others failed to measure it or report mortality of feeding insects. The use of plot cages does not allow for careful observation of individual insects, as mentioned in the introduction, and significant mortality may have occurred in our experiments. Restricting insect feeding through systematic insecticide applications and periodic sampling of adjacent untreated areas may provide an effective alternate system for measuring the density-damage relationship.

Post-harvest analysis of rice samples to distinguish between damage caused by RSB and other sources is critical to establishing a density-damage relationship. Samples must be hand-threshed because machine threshing removes blank grains and detached hulls. Likewise, samples should be analyzed for peck in the brown rice form prior to milling so that insect damage can be retained. Milled rice allows for the assessment of broken and chalky rice, although it is more difficult to correlate with RSB density. Future research to develop updated economic thresholds will require the combination of assessments in the rough, brown, and milled forms.

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CHAPTER 7: DEVELOPMENT OF IMMATURE *OEBALUS PUGNAX* F. (HEMIPTERA: PENTATMOIDAE) ON RICE AND THEIR IMPACT ON YIELD AND QUALITY OF LONG GRAIN RICE

Introduction

The rice stink bug, *Oebalus pugnax* F. (Hemiptera: Pentatomidae), is the late-season pest of primary concern for rice producers in the southern United States. Rice stink bugs use their piercing-sucking mouthparts to feed on rice panicles throughout the grain-filling process. As rice panicles develop, rice stink bug feeding damage is manifested in various ways: blank grains, reduced grain weight, broken grains, chalky grains, and discolored (pecky) rice. Adult stink bugs are winged and highly mobile, which allows them to invade rice fields soon after heading (at the first appearance of panicles) or quickly evacuate fields that are no longer ideal for feeding due to insecticide treatments or inedible panicles. Rice stink bug nymphs, in contrast, are wingless and confined to panicles on or near the plant on which they hatch.

Rice stink bug adults favor heading rice over their alternative host plants, graminaceous weeds, for feeding and egg laying (Douglas 1939, Odglen and Warren 1962, Nilakhe 1976, Way 2003, Rashid et al. 2005). Females often lay eggs on rice leaves, stems, and panicles immediately after moving into fields (Nilakhe 1976). Rashid et al. (2005) found that development time from egg to adult ranged from 249 to 281 degree days and 17.9 to 36.8 calendar days under controlled conditions in the laboratory. There is some variation in rate of panicle maturation among commonly grown conventional varieties in the South, but contemporary long grain varieties develop from 50% heading to maturation in approximately 30 to 45 days depending on weather conditions (Moldenhauer et al. 2013). Rapidly-maturing varieties may inhibit nymph development or result in small sized adults because the ability of bugs to feed on grains decreases as grains mature (Bernhardt unpublished).

Damage caused by rice stink bug adults feeding on rice during the flowering, milk, and dough stages of grain development has been well-documented over the last 100 years (Fulton 1908, Douglas and Tullis 1950, Swanson and Newsom 1962, Fryar 1986, Lee et al. 1993, Patel et al. 2006, Espino 2007). However, less attention has been given to the potential for damage by rice stink bug nymphs, and they are virtually ignored in insecticide treatment thresholds (Nilakhe 1976, Bowling 1979, Espino et al. 2007). Nilakhe (1976) examined the development of nymphs and pecky rice caused by feeding on commercial and experimental rice lines by caging nymphs on panicles and allowed them to feed for approximately two weeks after eclosion. Results showed significant differences in nymphal development time and pecky rice among varieties. Bowling (1979) found that rice stink bug nymphs (third to fifth instar) and adults feed at similar rates as evidenced by the number of feeding sheaths on infested rice grains. Espino et al. (2007) investigated the relationship of third to fifth instar nymph and adult feeding at various stages of panicle development. They concluded that nymphs are capable of causing peck, but at a lower level than adult rice stink bugs.

The purpose of this experiment was twofold: 1) to determine if yield loss and pecky rice are caused by rice stink bug nymphs after hatching on rice panicles at anthesis; 2) to determine if rice stink bugs, under field conditions, complete egg and nymph development before grains ripen to the point at which they are no longer susceptible to injury.

Materials and Methods

The experiment was carried out at the Louisiana State University Agricultural Center Rice Research Station in Crowley, LA, in small plots (1.8m x 5.4m) of rice (Cheniere cv.) planted in Crowley silt loam soil. Experiments were initiated when panicles began to emerge in these plots. Two replicates of the experiment were conducted, separated by three days. In both replicates, egg masses were caged on individual panicles and bugs were allowed to develop until adults began to appear in cages. Bugs were then removed, and damage to rice was assessed at grain maturity.

To obtain egg masses used for infestations, adult rice stink bugs were field collected by sweep net two weeks prior to heading of experimental rice plots and maintained in aquaria on moistened rice panicles in the laboratory. When needed, 1-2 day-old egg masses (Bernhardt 2009) were carefully peeled from oviposition sites on panicles and vegetation. Individual egg masses were placed in 1 oz plastic diet cups (Dart Corp.; Mason, Michigan) to facilitate transport to the field. The number of eggs in each mass was written on cups and the lid was secured. The first replicate was initiated on July 19th. For this replicate, 14 nylon tulle cages were placed over individual panicles at the R4 stage of panicle development with one or more florets at anthesis (Counce et al. 2000). Cages measured 34 cm x 10 cm and provided adequate room for insects to feed on all areas of the panicle. A 3.81cm x 2.54 cm merchandise tag (QC40004, Reliable; Chicago, IL) labeled with the date and number of eggs was then tied to the stem beneath the neck of the panicle. Eggs were carefully placed at the base of cages, and cages were secured with metal twist ties. A second replicate was initiated on July 22nd with twelve additional cages. For each infestation date, two panicles received cages without eggs and were designated as untreated controls for each replicate. Cages for both infestation dates were carefully removed from panicles on August 6th, when all insects were either nymphs in the fifth instar or adults. Adults had eclosed within 48 hours of cage removal. Rice panicles were in the hard dough stage of development, R7. Total nymphs and adults in each cage were recorded upon removal. Panicles were treated with a pyrethroid insecticide (Karate Zeon®, Syngenta Crop Protection, Greensboro, NC) immediately following cage removal and biweekly thereafter until rice was fully ripened. Mean daily temperature was taken from hourly recordings at the RRS for both replicates and degree-days were calculated using the x-intercept method (Arnold 1959) and a baseline threshold temperature of 14°C (Espino 2007).

Panicles were harvested at full maturity, the R9 stage (Counce et al. 2000), and allowed to dry at room temperature in paper bags before being hand threshed. After threshing, empty grains (blanks) were separated from filled grains. Grains were considered blanks if they appeared translucent on a light table or had an asymmetric shape. Partial hulls with no grain attached that separated from kernels during drying were also included in the blank category. Blanks and filled grains were weighed separately and counted for each panicle. Weights of blanks consisted mostly of empty hulls. Weights of blank and filled grains were summed to obtain a rough rice weight for each panicle. Blanks and filled grains were then dehulled (model MTH-35A, RIMAC; Hialeah, FL) and resulting sample weight of whole and partial kernels was taken. Blanks were included in the dehulling process to ensure that partially-filled grains with an abnormal appearance were accounted for in the final yield weight. Percent blank weight was calculated by dividing weights of blanks by rough rice weight. Percent brown rice was calculated by dividing weight of dehulled kernels by initial rough rice weight. Two additional measures of grain quality, percent peck and broken grains (grains less than 75% of typical kernel length), could not be assessed because the majority of samples were reduced to fragments that were too small to allow determination of peck or to be classified as partial grains according to USDA standards.

The relationship between total rice stink bug density (at cage removal) and both percentage blank weight and percent brown rice was determined using regression analysis in PROC REG of SAS (SAS Institute 2011). Data were analyzed separately for each of the two replicates to ensure regression models for both empty grains and brown rice yield were significant. Once this was confirmed, data for both replicates were combined for the final analysis.

Both percentage blank weight (Figure 7.1) and brown rice percentage (Figure 7.2) were individually tested for a linear relationship with total rice stink bug (RSB) number (adult + fifth-instar nymphs) as the independent variable in SAS (PROC GLM). The SAS procedure PROC UNIVARIATE was used to test for normality of rice stink bug distribution and to plot each dependent variable with the residuals of RSB. All tests showed that the distributions were normal using the Shapiro-Wilkes test for normality at a 95% confidence level.
Residual plots of rice stink bugs and both percentage blank weight and brown rice percentage were tested in SAS using PROC GLM. The residual plot for percentage blank weight and RSB showed a slight parabolic tail that indicated a possible curvilinear relationship. To investigate this relationship, a quadratic exponential variable (RSB*RSB) was added to the linear model to test a quadratic relationship of the dependent variable.

Results

Among the 23 panicles used for this study (two infestation dates), initial egg numbers ranged from 0 to 46 with a mean of 18.78 ± 0.50 eggs per panicle. One control panicle in the first replication resulted in a whitehead and data was not collected from it. An egg-infested panicle in the same replication had a 0% hatch rate. All eggs in that cage remained green throughout the experiment, which signified that embryos did not develop. This particular cage provided an additional data point for zero insects at termination of the experiment. Data from this panicle were also included in the calculations for insect survival.

A survival rate of 34.5% was observed among the 20 egg-infested panicles. Infested panicles averaged 2.20 ± 0.87 adults and 5.00 ± 1.08 fifth instar nymphs at the time of cage removal (Table 7.1). Although total egg number was higher for the second replicate (*n*=225), than the first replicate (*n*=207), the number of insects that hatched and survived until cage removal was lower in the second replicate (*n*=63) than the first (*n*=86). Likewise, the percent survivorship was higher in the first replicate (41.55%) compared to the second (28.00%) (Table 7.1). A larger proportion of adults were present in cages removed from the first replicate (63.64%) than those removed from the second replicate (36.36%). More panicles were infested on the first planting date (*n*=11) than the second date (*n*=9), but the average total insects removed from each panicle deviated by only 0.8 insects between the two replicates.

Table 7.1. Descriptive statistics for treatment variables for infested panicles for Replicate 1 (July 19th) and Replicate 2 (July 22nd).

Replicate	Initial Eggs		Surviving Adults		Surviving Nymphs		Total RSB	Percent Survival
	Total	Mean ± SEM	Total	Mean ± SEM	Total	Mean ± SEM		
#1 (n=11)	207	18.82 ± 1.17	28	2.55 ± 1.02	58	5.27 ± 1.21	86	41.55
#2 (n=9)	225	25.00 ± 3.36	16	1.78 ± 1.54	47	5.22 ± 1.93	63	28.00
Combined (n=20)	432	21.60 ± 1.74	44	2.20 ± 0.87	105	5.00 ± 1.08	149	34.49

Mean daily temperature for both replications was 28°C, and maximum temperature was 36°C. Minimum temperature was 22°C in the first replication and 23°C in the second replication. Degree-days were calculated at 274.8 days for the first infestation date and 235.7 days for the second.

A significant relationship was observed between total rice stink bugs at cage removal and both percent blank weight and percent brown rice (Table 7.2). The test of the quadratic model showed that RSB*RSB was a non-significant indicator (*P*= 0.5665) of percent blank weight. The linear model, percent blank weight = (4.496) + (total RSB number)*(2.171), was found to be significant (*p<.001)*. This result suggests that percent blank weight and RSB have a positive linear relationship (Figure 7.1). The total RSB present at cage removal was a significant indicator of percent blank weight (*P<.001)* and explained over 55.3% of the variance in percentage blank weight ($R^2 = 0.5535$). A negative relationship was observed between percent brown rice and total rice stink bugs at cage removal. The model, percent brown rice = (77.565) + (total RSB number)*(-4.863), was highly significant (*p*<.001) and explained over 85% of the variance in percent brown rice ($R^2 = 0.8545$) (Figure 7.2).

Table 7.2. Effects of total rice stink bugs (fifth instar nymph and adults) on two response variables, percent blank weight and percent brown rice, in two experiments.

Variable	*n*	Slope ± SE	*F*	*P*	R^2
Percent Blank Wt	23	4.496 ± 3.561	26.04	<0.0001	0.5665
Rep 1	13	6.670 ± 2.992	13.58	0.0036	0.5526
Rep 2	10	5.062 ± 6.194	15.04	0.0047	0.6528
Percent Brown Rice	23	77.565 ± 3.665	123.32	<0.0001	0.8545
Rep 1	13	73.423 ± 7.103	23.31	0.0005	0.6794
Rep 2	10	80.419 ± 2.565	325.76	<0.0001	0.976

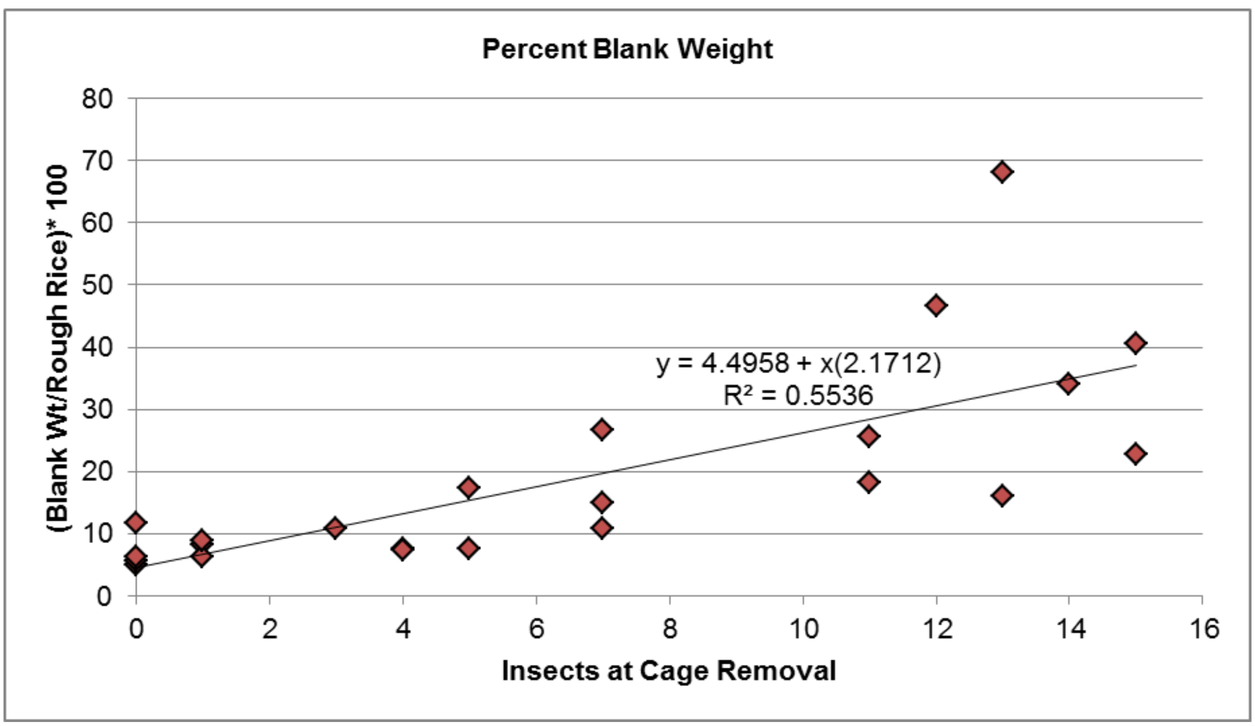

Figure 7.1 Relationship between total rice stink bugs (fifth instar nymphs and adults) at cage removal and percent blank weight. The relationship was determined using a total of 23 panicles infested at experiment initiation with varying numbers of eggs.

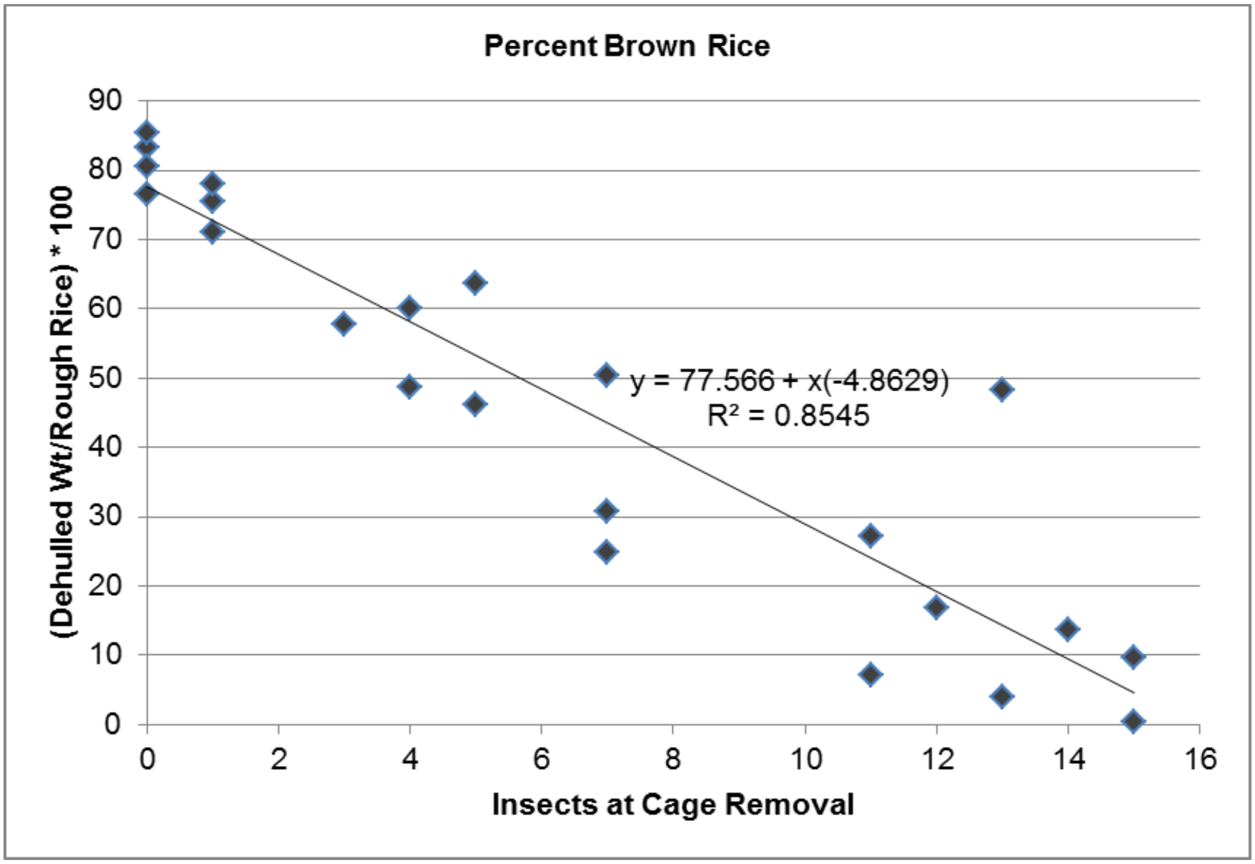

Figure 7.2 Relationship between total rice stink bug (fifth instar nymphs and adults) at cage removal and percent brown rice. The relationship was determined using a total of 23 panicles infested at experiment initiation with varying numbers of eggs.

Discussion

Rashid et al. (2005) determined that the time for hatching of rice stink bug eggs in the laboratory ranged from 3d at 37.8 ± 2°C to 11.2d at 21 ± 2°C, and development from egg to adult ranged from 17.9d to 36.8d at 29 ± 2°C and 21 ± 2°C, respectively. The lower threshold for determining degree-days for rice stink bug development from oviposition to eclosion was 14°C, and degree-day accumulation for the same life stages decreased from 281.1 to 249.4 days when temperature increased from 21 to 29°C. The results of the current study aligned closely with the data from Rashid et al. (2005) considering that rice stink bug eggs hatched and developed into adults at a mean temperature of 28°C in 235.7 and 274.8 degree-days or 16 and

19 calendar days in replicates two and one, respectively. Grain developed from the anthesis stage, R4, to the hard dough stage, R7, at a rate consistent with ranges noted by Moldenhauer et al. (2013) for tropical japonica long-grain rice. Thus, eggs laid on plants at roughly the same time as panicles emerge would easily develop to damaging late-instar or adult stages before rice matured.

The difference in proportion of adults and nymphs in the two infestation dates may be explained by the two day difference in time bugs spent in cages in the two replicates, but other factors may have influenced the variation. The highest numbers of insects surviving on a single panicle at cage removal was 15 and 16 for replicates one and two, respectively. This is likely not an upper limit for number of insects capable of surviving on a panicle, as an additional cage, which was not included in the analysis due to dehulling complications, contained 31 insects at cage removal. Field and weather conditions were similar for both infestation dates, and were unlikely the cause of reduced survivorship. Egg parasitoids can be effective at reducing hatch rate in rice stink bugs (Swanson 1960, Sudarsono 1989), and *Beskia aelops* were commonly seen in plots at the RRS in 2013. Cages likely shielded most eggs in the study from parasitoids. However, a survey of parasitoids or parasitism rates was not recorded to confirm the role parasitoids may have played in the variation in survivability between infestation dates.

Rice stink bug nymph feeding habits and damage were previously investigated by Bowling (1979) and Espino et al. (2007). The Bowling (1979) study saw a similar number of salivary feeding sheaths on grains fed upon by adult or late instar nymphs in his study, but the amount of feeding that resulted in actual damage leading to yield loss was not determined. Espino et al. (2007) sought to determine the relationship between rice stink bug feeding, pecky rice, and blanks when nymphs and adults fed at various points during panicle development in their study.

Although adults caused damage in most instances in that study, nymphs failed to cause peck at levels significantly higher than controls. Adults and nymphs were seen to increase weight of empty grains when infestation occurred at heading rather than soft dough in the first year of their study, but the same effect was not seen in nymphs the second year. Only adult feeding led to an increase in blank weight significantly different from controls in either year.

Both Bowling et al. (1979) and Espino et al. (2007) investigated the effect of nymph feeding on damage by infesting plants with low levels of insects not typical of egg hatchings. Both studies compared adult and nymph feeding without addressing the issue of damage by early developing nymph cohorts. A determination of the effects of natural nymph populations on yield in field experiments was needed to investigate damage for the purpose of including eggs and nymphs in sampling strategies. Using egg masses to determine the likelihood of nymphs developing into adults and the subsequent damage they cause during that time provided a more realistic assessment of the potential of nymphs to damage developing rice.

The relationship between nymph feeding and both weight of blank grains and percent brown rice were highly significant in the current study (Table 7.1). At the mean survival level, 7.9 insects, regression models predicted a 17.14% increase in weight of blank grains and a 38.42% reduction in percent brown rice compared to non-infested panicles. These data highlight not only the need for continued sampling of fields from the early heading stage until hard dough, but also the inspection of rice panicles for the presence of rice stink bug egg masses in the early stages of heading.

The results of this study clearly demonstrate rice stink bug eggs deposited at or near time of heading can mature quickly enough to cause significant economic damage to developing panicles of rice. For this reason, eggs and nymphs present on rice plants at anthesis should be factored into threshold estimates when making insecticide application decisions in the first two weeks of rice panicle development. Currently, sampling for the presence of eggs is not recommended by the Cooperative Extension Service in any rice-producing state for estimating rice stink bug populations in rice fields. Further experiments should investigate nymph development and damage by instar and reproductive plant stage to determine if eggs deposited before or after anthesis provide adequate conditions for nymphs to cause damage. Studies to determine actual nymph distribution within field would be advantageous for determining dispersal rates during the early stages of rice panicle development.

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CHAPTER 8: USE OF INTERNET BASED STREAMING VIDEOS TO EDUCATE RICE PRODUCERS IN RECOMMENDED INTEGRATED PEST MANAGEMENT SAMPLING PRACTICES

Introduction

Streaming internet videos on sites such as YouTube and Vimeo are watched by billions of people throughout the world on a weekly basis, and agriculture-related businesses are making the most of this expanding field with multimedia sites like AgPhd.com, AgWired.com, Agriculture.com, and AgWeb.com. The use of streaming data on farms is not a new trend. Farmers have been subscribing to weather and commodity news satellite services since the 1980's. Surveys have shown that with increased affluence and Internet accessibility, the use of Internet-based agricultural resources is more prevalent (Howell and Habron 2006). Since that study was published, the iPhone and YouTube entered the market and increased accessibility to the internet and video-based entertainment and education tools. Mobile internet is used for almost 40% of total viewing time at YouTube.com (2014).

Survey data from the Louisiana State University Agricultural Center (LSU AgCenter) (Natalie Hummel unpublished) in 2008 and 2009 showed growing use of smartphones by members of the rice industry in Louisiana. To confirm these findings, discussions were held with producers and crop consultants in 2011. Participants established that a need existed for streaming instructional videos that could be accessed in the field via smartphone to help make pest management decisions.

Materials and Methods

Production plans were initiated in the spring of 2011 to locate a filming site and to determine necessary content of the videos to be filmed. Two sites in Acadia Parish were selected for filming where rice was in the milk to soft dough stage and rice stink bugs had been observed feeding. Filming took place July 26, 2011 by Craig Gautreaux of the LSU AgCenter Communications Department. Footage was edited and combined with photos and text to produce three separate videos focused on RSB scouting technique and management, timing of RSB scouting, and RSB biology. Videos were uploaded to YouTube.com on March 30, 2012.

Results

Three videos were produced using the footage recorded on March 30th (Table 8.1). Each video was less than three minutes in length. Daily view statistics show that videos were viewed more frequently from July to August in 2012 and 2013, which coordinated with the typical heading period of rice in Louisiana.

Table 8.1 Viewing statistics and links to sampling videos.

Video Title	YouTube Link	Total views on 5/9/2014
Scouting and management for rice stink bug	http://www.youtube.com/watch?v=2MFHLRh3AOo	120
Life cycle of the rice stink bug	https://www.youtube.com/watch?v=4ijb8fxsseM	532
Determining the proper time to scout for the rice stink bug	http://www.youtube.com/watch?v=8kBFTopdpwU	139
Injuries caused by the rice stink bug	http://www.youtube.com/watch?v=IcHTtfuYjMU	85

Discussion

Web-based videos are able to fill many niches in extension education programs previously filled by multiple media methods. Traditional visual aids in extension education consisted of poster displays of film photographs, slide projectors, and overhead projectors. Extension specialists in many areas relied on local radio and television stations to reach large audiences before the Internet became widespread. In more rural areas of the US the nearest television stations may be hundreds of miles away. Providing timely video and audio recordings of educational material tailored for a specific target group is still not possible in the most rural agricultural communities in the US, but the growth of Internet access is increasing the reach of extension education material. Recent surveys showed that the majority of Louisiana farmers acquire IPM information from consultants. Louisiana consultants helped drive the decision to produce these rice IPM videos during the planning phase. The information sharing relationship between farmers and consultants in Louisiana suggests that the information presented will actually effect a larger population than viewer statistics can show. Surveys of farmers and consultants may help to gauge overall impact of videos and assist specialists in planning and producing more effective videos in the future.

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CHAPTER 9: SUMMARY AND CONCLUSION

The rice stink bug (RSB), *Oebalus pugnax* F., is the primary late-season pest in rice grown in the southern United States. Managing the insect on an area-wide basis is complicated by the fact that it feeds on sorghum, wheat, and grassy weeds that are ubiquitous across the same region. Numerous hosts provide RSB populations alternative options when weeds are destroyed or crop hosts are treated with insecticides. Surveys have shown that in the last 15 years, pyrethroid insecticides have been favored over organophosphates and carbamates by rice producers in the southern US. Populations of RSB in Texas are reportedly treated more frequently than populations in other states, and tests in 2008 had suggested these insects may have developed a high tolerance for pyrethroids. Few affordable and effective alternatives are currently available to encourage producers to rotate insecticide chemistries. Additionally, the current treatment thresholds recommended in Louisiana have been used for over 30 years without reevaluation for new varieties and crop production methods.

The purpose of experiments carried out from 2010 to 2013 was to evaluate the current status of integrated pest management (IPM) options currently recommended to prevent economic damage by RSB adults and nymphs in Louisiana. The multi-season project resulted in: updated insecticide recommendations, a rate of RSB sweep-net sampling efficiency, RSB density-damage data, a recent record of farmer IPM practices, and improved educational tools. Field experiments were conducted from 2010-2013.

The first objective of this research assessed the efficacy of several currently labeled insecticides and a neonicotinoid insecticide on control of RSB. The neonicotinoid insecticide was similar to pyrethroid products used most by rice producers in Louisiana in tests measuring feeding behavior, exposure mortality, and density reduction. The tested product has since been labeled for use in Louisiana rice. The organophosphate malathion had been used longer than any other product for RSB management in rice, and it was shown to be highly ineffective. Glass-vial bioassays showed elevated levels of pyrethroid tolerance in a Texas RSB population compared to a population from the LSU Rice Research Station in Crowley, LA. The data from these experiments has been accepted for publication in a refereed journal, Entomological Society of America Arthropod Management Tests, and multiple LSU AgCenter Rice Research Station Reports.

The second objective of our research evaluated the density-damage relationship for rice stink bugs feeding in rice through cage studies. Sweep-net sampling efficiency was also determined to aid in determining cage densities in relation to current thresholds. The data suggests that sweep nets collect approximately 20% of RSB adults when used according to LSU AgCenter recommendations. This rate of recovery is much less than previous estimates determined by counting visible insects and correlating with sweep-net samples in the same fields (Bowling 1969). Although cage studies did not result in updated thresholds, they will be used as a resource in the design future multi-state collaborative experiments to characterize the density-damage relationship of RSB feeding on rice. Previous cage studies also failed to show a relationship among tested densities and various forms of damage. Feeding by RSB nymphs was characterized in field cage studies, and results showed a negative correlation (R^2=0.8545) between nymph feeding and brown rice recovery. Previously, only adult RSB were included in Louisiana threshold recommendations. Future thresholds will be modified to include eggs and nymphs in early season sampling recommendations.

The third research objective focused on assessing the adoption of recommended IPM practices by rice-industry professionals in southern rice producing states and producing original internet-based delivery of extension recommendations for RSB management. The first of these criteria was met through a multi-state survey of producers (n=851) to assess on-farm practices for the 2008-2012 seasons. Our surveys showed that producers in Louisiana and Texas used pyrethroid insecticides more frequently than all other labeled products for RSB control, and growers in Texas averaged more pyrethroid applications per season for RSB control than respondents in other states. Newly labeled seed treatments to combat rice water weevils were adopted by the majority of respondents in all states surveyed. Understanding how insecticides are being used allows extension researchers and specialists to gauge whether their results are being effectively communicated to the target audience. The second aspect of the objective was realized by creating a streaming video highlighting the biology and sampling procedures for the RSB in rice. Delivering extension recommendations to the public through the use of current appropriate technology is becoming more necessary as younger farmers, consultants, and extension agents become involved in rice production. Streaming video is just one in a growing list of media that can be utilized for effective delivery of information to the growing demographic of farmers who access rice production guidelines on smartphones and tablets.

The combination of field-based IPM research, industry surveys, and digital education content contribute greatly to the mission of extension entomology by bringing research-based IPM information to producers outside the traditional classroom for the purpose of improving the content and quality of Louisiana agriculture for both farmers and consumers. The results of our studies helped to establish the efficacy of popular insecticides used against the RSB, documented changes in rice pest management practices, and contributed to the current body of knowledge on the density-damage relationship of RSB adults and nymphs.

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VITA

Bryce D. Blackman was born and raised in Craighead County, Arkansas, not far from the site where rice production was first documented in the state. His family involvement in production agriculture in Southeast Missouri inspired him to pursue opportunities in agriculture-related projects in 4-H and FFA while attending elementary and high school. An interest in science and education inspired him to pursue undergraduate and graduate degrees in agriculture at Arkansas State University and the University of Arkansas, respectively. Following two years as a County Extension Agent in northeast Arkansas, he enrolled at Louisiana State University and Agricultural and Mechanical College to pursue a doctorate in entomology. Bryce began working in international agricultural extension, research, and development as a professional officer at the International Rice Research Institute in the Philippines in the summer of 2014.