

EFFICACY OF DERMACOR-X-100® SEED TREATMENT AGAINST *DIATRAEA SACCHARALIS* (LEPIDOPTERA: CRAMBIDAE) ON RICE

JASPREET K. SIDHU¹, JARROD T. HARDKE² AND MICHAEL J. STOUT^{1,*}

¹Department of Entomology, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, USA

²Rice Research & Extension Center, University of Arkansas, Stuttgart, AR 72160, USA

*Corresponding author; E-mail: MStout@agcenter.lsu.edu

ABSTRACT

The sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), which attacks sugarcane, corn, sorghum, sudan grass and rice, is a major agronomic pest in the southeastern United States. This study was conducted to investigate the efficacy of different rates of Dermacor-X-100® (active ingredient, chlorantraniliprole) seed treatments on *D. saccharalis* in rice in the laboratory, greenhouse and field. In laboratory assays using cut stems, Dermacor-X-100® resulted in 40-50% more mortality than in the control, while in greenhouse intact plant assays Dermacor-X-100® resulted in approximately 70-80% higher mortality compared to controls. In the field study, Dermacor-X-100® seed treatment resulted in significantly lower numbers of borer entry and exit holes per plant. Results from this study suggest that Dermacor-X-100® seed treatment could be used as a valuable component of integrated pest management program for stem borers in Louisiana rice. As the boring behavior of larvae, life cycle and injury caused by most stem borers are generally similar, and because the active ingredient in Dermacor-X-100® is highly efficacious against lepidopteran pests, results for *D. saccharalis* may extend to management of other stem boring species as well.

Key Words: chlorantraniliprole, seed treatment, sugarcane borer, rice

RESUMEN

El barrenador de la caña, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), que ataca la caña de azúcar, el maíz, el sorgo, el pasto sudán y el arroz, es una de las principales plagas agronómicas en el sureste de los Estados Unidos. Se realizó este estudio para investigar la eficacia de diferentes tasas de tratamientos de semillas con Dermacor-X-100® (ingrediente activo, clorantraniliprol) contra *D. saccharalis* sobre el arroz en el laboratorio, invernadero y campo. En ensayos de laboratorio utilizando tallos cortados, Dermacor-X-100® resultó en una mortalidad del 40-50% más que en el control, mientras que en los ensayos de invernadero con plantas intactas, Dermacor-X-100® resultó en una mortalidad de aproximadamente del 70-80% mayor en comparación con los controles. En el estudio de campo, el tratamiento de semillas con Dermacor-X-100® resultó en un número significativamente más bajo de agujeros de entrada y salida de los barrenador por planta. Los resultados de este estudio sugieren que el tratamiento de semillas con Dermacor-X-100® podría ser utilizada como un componente valioso en un programa de manejo integrado de plagas para los barrenadores del tallo del arroz en Louisiana. Como el comportamiento de las larvas, el ciclo de vida y de daño causado por la mayoría de los barrenadores del tallo son generalmente similares, y debido a que el ingrediente activo en Dermacor-X-100® es altamente eficaz contra plagas de lepidópteros, los resultados de *D. saccharalis* puede extenderse al manejo de otras especies de barrenadores.

Palabras Clave: clorantraniliprol, tratamiento de semillas, barrenador de la caña, arroz

Stem borers have historically been considered important pests of rice in Louisiana and Texas (Douglas & Ingram 1942; Oliver et al. 1972). Their incidence decreased in the 1980's, probably as a result of the use of cultivars with greater resistance, improved cultural practices and the extensive use of insecticides for stink bug management

(Way 1990). The use of insecticides against stem borers was rarely justified during this period. In recent years, however, farmers have experienced an increase in stem borer infestations due to increased adoption of minimum tillage and several years of mild and dry winters (Castro 2004; M.O. Way, personal communication).

The stem borer complex attacking rice (*Oryza sativa* L.; Poales: Poaceae) in the southern U.S includes the sugarcane borer (SCB), *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), the rice stalk borer, *Chilo plejadellus* Zincken (Lepidoptera: Crambidae), and an invasive species, the Mexican rice borer (MRB), *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae: Crambinae). The SCB is an economically important pest of graminaceous crops in Texas and Louisiana (Bowling 1967; Roe et al. 1981; Way et al. 2006). The SCB has been reported on more than 20 hosts (Holloway 1928). In 2002, this pest infested more than 1,200 ha of rice in Concordia parish in Louisiana and caused 75-95% crop loss on some farms (Castro 2004). Way et al. (2006) reported that stem borer injury caused up to 60% yield losses in untreated rice fields in Texas and, among all the stem borers recovered from their field samples, 60% were sugarcane borers. MRB was first discovered in the Lower Rio Grande valley of Texas in 1980 and since its detection in 1980 has become the dominant insect pest of sugarcane (Johnson 1984). By the end of 1980's its geographic range had gradually expanded into the rice producing area of Texas (Browning et al. 1989) and has subsequently caused large yield losses across the Texas rice belt (Reay-Jones et al. 2005). The Mexican rice borer has invaded Louisiana in 2008 from eastern Texas (Hummel et al. 2010) and has steadily expanded its range since (Stout, unpublished data). The MRB has the potential to cause heavy economic losses if it becomes established in areas where rice and sugarcane are grown (Reay-Jones et al. 2008).

Foliar insecticide applications have always been the primary control tactic for managing stem borer infestations and yield losses in Texas (Browning et al. 1989; Reay Jones et al. 2007). Over the past few years stem borer control has been accomplished using pyrethroids applied as foliar sprays during the reproductive phase of rice development with one application at 1-2 inch (2.5-5 cm) panicle exertion followed by another at late boot or early heading (Reay Jones et al. 2007a; Way & Espino 2010). There are several issues with the use of pyrethroid sprays. General negative aspects of the use of foliar pesticides include pest resurgence, hazards to users, environmental contamination and costs associated with multiple applications. For stem borers in particular, the damaging stage is the larva, which is an internal feeder that remains concealed inside the stem, where reduced contact with foliar insecticides limits efficacy (Litsinger et al. 2005). In addition, there are no economic thresholds for stem borers in rice, making it difficult to determine when to treat and perhaps leading to the overuse of insecticides. Research on the use of insecticides to manage stem borers in the USA has been sparse (Browning 1989; Way 2003). Because of the risk

of resistance development and limited research, it is essential to investigate new chemistries as alternatives to existing conventional insecticides.

Chlorantraniliprole is a relatively new insecticidal active ingredient. Seed treatment with Dermacor-X-100®, which contains chlorantraniliprole as the active ingredient, is widely used against the rice water weevil, the most important early-season pest of rice in the USA (Lanka et al. 2012). Chlorantraniliprole is an anthranilic diamide that targets ryanodine receptors located on the sarcoplasmic reticulum of muscle cells, and that leads to Ca⁺⁺ depletion, feeding cessation, lethargy, muscle paralysis and ultimately death in insects (Cordova et al. 2006, 2007). Chlorantraniliprole is a systemic insecticide and generally persists in plants for long periods of time (Lahm et al. 2009). Thus, the use of chlorantraniliprole as a seed treatment could potentially affect stem borer larvae feeding inside rice stems. The objective of the present study was to investigate the efficacy of different rates of Dermacor-X-100® seed treatments on *D. saccharalis* in rice.

MATERIAL AND METHODS

Laboratory and Greenhouse Studies

Diatraea saccharalis larvae used in these experiments were obtained from a colony maintained continuously in the laboratory at Louisiana State University following the methods of Martinez et al. (1988). The colony originated from larvae collected in rice fields near Crowley, Louisiana, in 2005. Larvae were reared in 29.5 mL Solo soufflé cups (AceMart Restaurant Supply, San Antonio, Texas) on sugarcane borer artificial diet (Southland Products, Lake Village, Arkansas). Pupae were sexed following Butt & Cantu (1962) and equal numbers of males and females were placed into 3-L plastic buckets with wax paper as a substrate for oviposition. Adults were provided with a 1:1 mixture of honey and beer (Milwaukee's Best Light, Miller Brewing Co., Milwaukee, Wisconsin) and distilled water. Eggs were put into 8-cell plastic trays (C-D International, Pitman, New Jersey) for hatching with a moistened cotton ball inside each cell. When the eggs hatched, neonates were placed on the artificial diet in soufflé cups and reared until use. The colony was maintained under controlled environmental conditions (28 °C ± 2 °C; 30% RH). Insects collected from rice fields were added annually to the colony to maintain genetic variability.

Seeds of the commonly grown conventional rice cultivar 'Cocodrie' were used for all experiments. Seeds were treated with Dermacor-X-100® (DuPont Crop Protection, Denver, USA) by diluting this formulated insecticide in water containing a small quantity of brilliant blue dye and applying this diluted material to seeds in Ziploc® bags

to attain the desired treatment rates. Different treatment rates used in these studies are listed in Table 1. The lowest rate used in this study (66 g ai/100 kg seed or approximately 0.03 mg ai/seed) corresponds to the lower limits of recommended field rates used in Louisiana against rice water weevil (DuPont 2011). The 0.06 and 0.09 mg ai/seed treatment rates are higher than the label rates for Dermacor-X-100®.

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

Laboratory Assays

The efficacy of Dermacor-X-100® against *D. saccharalis* larvae was investigated in laboratory experiments using cut stems and leaves in 2010 and 2011. In 2010 a single rate of Dermacor-X-100® was used for seed treatment (Table 1). When greenhouse-grown plants reached the mid-tillering stage (40 days after planting), they were brought back to the laboratory for experiment initiation. For the stem assays, 5 stem pieces, each about 10 cm long, were cut from the central (primary) tiller of each of the 15 treated and 15 untreated plants. The 5 stem pieces from each plant were placed in 14 × 2.5 cm petri dishes (Corning™, New York) lined with wet filter paper. For the leaf assays, 5 leaf pieces, each approximately 10 cm long, were cut from a separate set of 15 treated and 15 untreated plants and placed into large petri dishes separately. The experiment was conducted as a randomized block design (RBD) with 15 replications. A block was a rack

with petri dishes arranged randomly on it. In each block there were 4 petri dishes, 1 of each treatment by plant tissue combination. Five first-instar larvae within 1-2 days of hatching were released into each petri plate. The larvae had been removed from artificial diet and starved for 3 hours prior to release in the petri dishes with plant tissue. The petri plates were then sealed with parafilm (Beemis flexible packaging, Neenah, Wisconsin) to prevent larval escape. After 72 h, stems and leaves were dissected and inspected for dead and live larvae. The number of living and dead larvae in each petri plate was counted and the percent mortality was calculated. Mortality was defined as lack of movement by larvae and no response to stimulation with a camel hair brush.

In 2011, 3 different treatment rates of the insecticide were used along with the untreated controls (Table 1). The experiment was conducted at 2 stages of rice plant development: mid-tillering (45-day old) and late tillering (60-day old). Eight-cell plastic trays (C-D International, Pitman, New Jersey) were used in this experiment instead of petri plates. The plastic trays were 40 cm long × 20 cm wide, divided into 8 cells. When the greenhouse grown plants reached the appropriate age, they were brought back to the laboratory for experiment initiation. Stem and leaf pieces about 6 cm long were cut from the treated and untreated plants as described above. In the 8-cell plastic trays, 4 cells contained leaf tissue and 4 cells contained stem tissues (1 cell for each insecticide rate). The experiment was conducted as a randomized block design (RBD) with 7 replications for 45-day old plants and 8 replications for 60-day old plants with each plastic tray considered a replication. Leaves and stems were infested by releasing 10 first instars into each cell. The cells were sealed using plastic covers (C-D International, Pitman, New Jersey). The 8-cell trays were placed in the insect rearing colony room (28 ± 2 °C; 30% RH). After 72 h, stems and leaves were dissected and inspected for dead and live larvae. Numbers of living and dead larvae in each petri plate were counted and percent mortal-

TABLE 1. DERMACOR -X-100® RATES AND RICE PLANT AGES USED IN LABORATORY AND GREENHOUSE EXPERIMENTS IN DIFFERENT YEARS.

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

*0.03 mg ai/ seed represents a field rate of 0.06 lb a.i per acre (0.067 kg/ha) at a seeding rate of 90 lbs per acre (100.9 kg/ha).

ity was calculated. Mortality was defined as lack of movement by larvae and no response to stimulation with a camel hair brush.

Data for laboratory assays in 2010 were analyzed as a factorial RBD experiment with block as a random effect and treatment and plant tissue as fixed effects using a mixed model analysis of variance in PROC MIXED (SAS Institute 1999). Data from the 2011 experiments were analyzed separately for 45- and 60-day-old plants in a manner similar to the 2010 data.

Greenhouse Studies

Two similar no-choice greenhouse studies using intact plants were conducted in 2012 to investigate the efficacy of Dermacor-X-100® seed treatments against *D. saccharalis* larvae. Three insecticide rates were used along with the untreated control (Table 1). The experiment was conducted as a RBD with 5 replications. Blocks consisted of groups of 4 plants, 1 plant from each treatment, spatially arranged on a greenhouse bench. When the plants reached the late tillering stage (50-55 days after planting) plants were infested using 5 first instars per plant. Small plastic clear tubes (Icon Plastics, California) were used as cages to confine insects on the plants. These tubes were 15 cm long and 2.5 cm in diam. They were placed over the primary tiller of each plant and foam plugs (WVR International, Suwanee, Georgia) were used to seal the top and bottom of the tube cages enclosing the stem. After 7 days, the plants were cut near the soil line using scissors. All stems were dissected and inspected for live and dead larvae. Numbers of living and dead larvae in each plant were counted and percent mortality was calculated.

Data for the 2 similar greenhouse studies in 2012 were analyzed together as a replicated RBD with block as a random effect and treatment as

a fixed effect using a mixed model analysis of variance in PROC MIXED (SAS Institute 1999). Means were separated using Tukey's HSD test (Tukey 1953).

Field Study

A field study was conducted in 2009 at the Louisiana State University Agricultural Center Macon Ridge Research Station, Winnsboro, Louisiana, to assess the potential impact of Dermacor-X-100® seed treatment on stem borer injury and to compare its efficacy with 10 other insecticide treatments. The study was conducted as a RBD with 4 replications. Rice seeds of the borer-susceptible cultivar 'Cocodrie' (Way et al. 2006) were drill-seeded at 100 kg/ha in plots measuring 8 rows (20 cm spacing) × 4.57 m long plot on 24 Jun 2009. Permanent flood was established on 28 Jul. Standard agronomic practices for drill-seeded rice in Louisiana were followed (Blanch et al. 2009). Insecticide treatments and rates are listed in Table 2. Applications of foliar insecticides were made when rice was at the 5 cm panicle elongation stage (Vergara 2001) by a CO₂ backpack sprayer with TX-8 nozzles at a pressure of 45 psi (310 kpa) at 3 miles/h (4.8 km/h) and a volume delivery rate of 10 gallons per acre (112.3 L/ha). At the time of application, heavy sugarcane borer infestations were observed in fields adjoining the field used for this trial. Before harvest, 4 plants were randomly sampled from each plot to assess SCB injury to rice. Injury assessment was based on the total number of entry and exit holes observed in the stems of sampled plants.

Treatment effects on the total number of holes per plant were analyzed using a one way analysis of variance for a RBD in PROC MIXED (SAS institute 1999) with treatment as a fixed effect and replication as a random effect. Means were separated using Tukey's HSD test (Tukey 1953).

TABLE 2. INSECTICIDES, RATES AND APPLICATION METHODS USED IN THE FIELD STUDY IN 2009 ON SUGARCANE BORER CONTROL ON 'COCODRIE' RICE AT WINNSBORO, LOUISIANA.

Insecticide	Trade name	Common name	Application	Rate
Centric		Thiamethoxam	Foliar	0.03 lb ai/acre
Belay		Clothianidin	Foliar	0.75 lb ai/acre
Control				
Coragen		Chlorantraniliprole	Foliar	0.04 lb ai/acre
Cruiser		Thiamethoxam	Seed treatment	0.03 mg ai/seed
Cruiser + Karate		Thiamethoxam+Lambda-cyhalothrin	Seed treatment+ foliar	0.03 mg ai/seed + 0.04 lb ai/acre
Cruiser + Coragen		Thiamethoxam+ Chlorantraniliprole	Seed treatment+ foliar	0.03 mg ai/seed + 0.04 lb ai/acre
Dermacor-X-100®		Chlorantraniliprole	Seed treatment	0.06 lb ai/acre
Tenchu		Dinotefuron	Foliar	0.13 lb ai/acre
Endigo		Lambda-cyhalothrin+ Thiamethoxam	Foliar	0.03 lb ai/acre
Karate		Lambda-cyhalothrin	Foliar	0.04 lb ai/acre

RESULTS

Laboratory Studies

In 2010, feeding by *D. saccharalis* larvae on both stems and leaves of Dermacor-X-100® treated plants resulted in significant mortality of larvae after a 72 h feeding period ($F = 43.62$; $df = 1,56$; $P < 0.001$). Larval mortalities were twice ($60.00 \pm 3.12\%$) as high on plant tissues from Dermacor-X-100® treated plants as on control plant tissues ($30.00 \pm 3.12\%$). Larval mortalities on stems ($45.33 \pm 3.12\%$) and leaves ($44.66 \pm 3.12\%$) did not differ significantly ($F = 0.02$; $df = 1, 56$; $P = 0.88$), and the interaction between plant tissue and insecticide treatment was not significant ($F = 0.19$; $df = 1,56$; $P = 0.66$).

In 2011, on 45-day old plants, seed treatment using Dermacor-X-100® increased larval mortalities ($F = 3.17$; $df = 3,48$; $P = 0.03$), but only the 2X rate of Dermacor-X-100® caused mortality significantly higher than the control (Fig. 1). Mortalities did not differ on stems and leaves ($F = 0.53$; $df = 1, 48$; $P = 0.47$), and the interaction between plant tissue and treatment was not significant ($F = 1.60$; $df = 3,48$; $P = 0.20$). Larval mortality was highest (25.0%) on plants grown from seeds treated with the 2X rate of Dermacor-X-100® and was approximately double the mortality on control plants (12.9%).

Similarly, on 60-day old plants, Dermacor-X-100® seed treatments resulted in higher larval mortality compared to the control ($F = 4.31$; $df = 3, 56$; $P < 0.008$) (Fig. 2). Larvae feeding on plants treated with the 2X rate of Dermacor-X-100® suf-

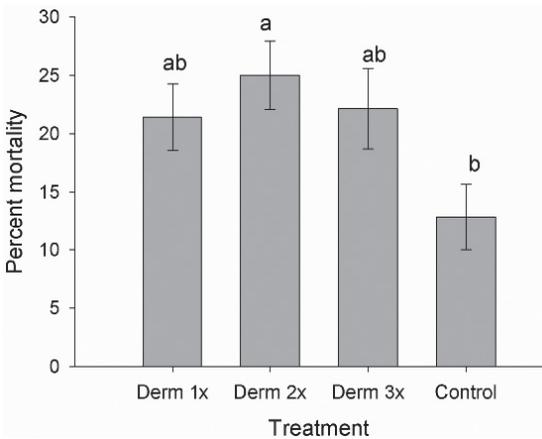


Fig 1. Mean ± SE sugarcane borer larval mortality on Dermacor-X-100®-treated and control plant tissues of 45 day old plants in the laboratory in 2011. The Derm 1x rate was Dermacor-X-100® applied at 0.03 mg ai/seed, which represents a field rate of 0.06 lb a.i. per acre (0.067 kg/ha). Means accompanied by different letters indicate a significant difference ($P < 0.05$).

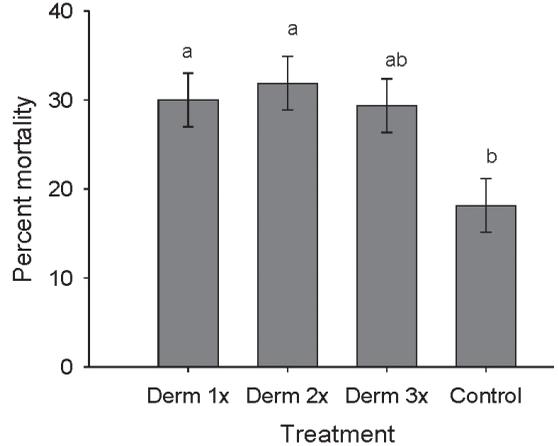


Fig 2. Mean ± SE sugarcane borer larval mortality on Dermacor-X-100®-treated and control plant tissues of 60 day old plants in the laboratory in 2011. The Derm 1x rate was Dermacor-X-100® applied at 0.03 mg ai/seed, which represents a field rate of 0.06 lb a.i. per acre (0.067 kg/ha). Means accompanied by different letters indicate a significant difference ($P < 0.05$).

ferred the highest mortality (31.87%) followed closely by the 1X rate (30.00%) and mortalities on these treatments were significantly higher than on the control, in which 18% larval mortality occurred. The 3X rate of Dermacor-X-100® was not significantly different from the control. There was no difference in larval mortality on plant parts (stems and leaves) ($F = 1.83$; $df = 1, 56$; $P < 0.18$). The treatment*plant part interaction was not significant for larval mortality ($F = 0.99$; $df = 3, 56$; $P = 0.40$).

Greenhouse Studies

In 2012, Dermacor-X-100® seed treatments were highly effective in the greenhouse no-choice studies using control and Dermacor-X-100® treated intact plants ($F_3 = 21.58$; $df = 3,36$; $P < 0.0001$) (Fig. 3). All 3 rates of Dermacor-X-100® caused significantly higher mortality than the control. Larval mortalities resulting from feeding on treated plants was highest in the 3X treatment and ranged from 60- 80% on the treated plants compared to 18% in the control.

Field Study

Numbers of borer entry/exit holes per plant differed among insecticide treatments ($F = 4.12$; $df = 10,33$; $P < 0.001$) (Fig. 4) and none of the insecticide treatments were as effective as the Dermacor-X-100® seed treatment. Numbers of entry/exit holes in Dermacor-X-100® treated plants were approximately 13 times lower than the control plants and significantly lower than numbers

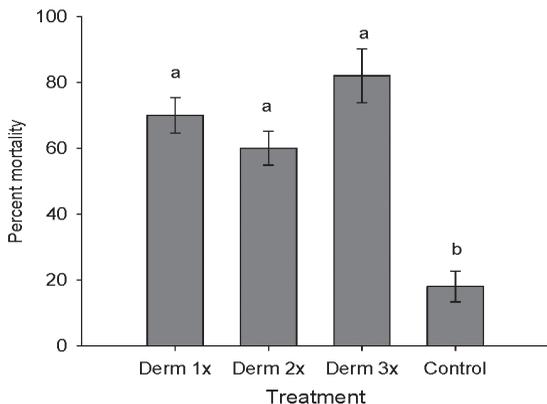


Fig 3. Mean ± SE sugarcane borer larval mortality on 60 day old intact plants in the greenhouse in 2012. The Derm 1x rate was Dermacor-X-100® applied at 0.03 mg ai/seed, which represents a field rate of 0.06 lb a.i per acre (0.067 kg/ha). Means accompanied by different letters indicate a significant difference ($P < 0.05$).

of entry/exit holes in all other insecticide treatments except Endigo, Dinotefuron and Cruiser+Karate. Numbers of entry/exit holes per plant

were numerically-but not significantly-highest in the Centric treatment and the untreated control.

DISCUSSION

The stem borers, *D. saccharalis* and *C. plejadellus*, have historically been considered important insect pests in Louisiana rice (Douglas & Ingram 1942; Oliver et al. 1972), and serious infestations of these insects have been reported over the last decade in Louisiana (Castro et al. 2004; MJS personal observation). Moreover, now another invasive stem borer species, *E. loftini*, has moved through the Texas rice belt into Louisiana as was predicted by Reay-Jones et al. (2008). This species was first found in 2008 from 2 pheromone traps in Louisiana, approximately 8 km from a rice field near the Texas border (Hummel et al. 2010). Reay-Jones et al. (2008) predicted an annual loss of up to \$45 million by Mexican rice borer assuming the entire rice industry will be infested by this pest by 2035. Despite the importance of stem borers in the past and their likely importance in the future, there is currently no sound management program for stem borers in

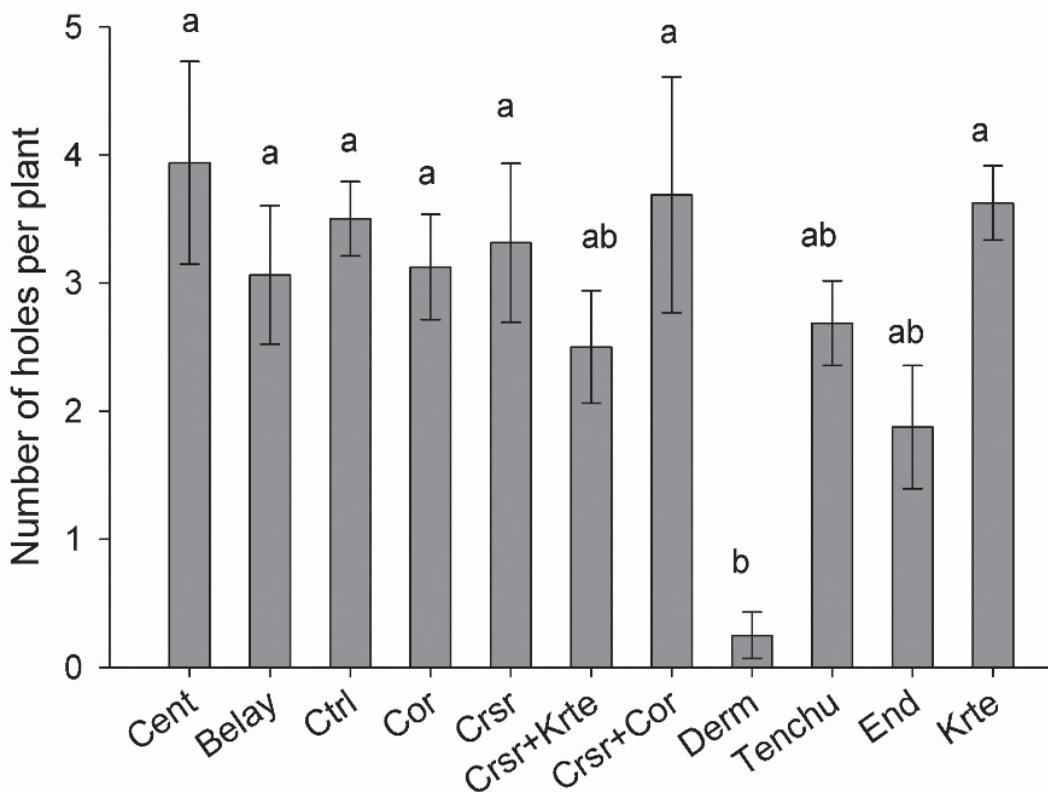


Fig 4. Mean ± SE number of borer entry/exit holes per plant on 10 different insecticide treatments of rice in the field study in 2009. Methods and rates of application are presented in Table 2. Means accompanied by different letters are significantly different ($P < 0.05$).

Louisiana. This study was conducted to evaluate the efficacy of different rates of Dermacor-X-100® against *D. saccharalis*. In the laboratory assays using cut stems, Dermacor-X-100® resulted in 40-50% more mortality than occurred in the control, while in the intact plant assays Dermacor-X-100® resulted in 78 % more mortality. In the greenhouse and laboratory studies, all rates of Dermacor-X-100® seed treatment caused significant mortality in intact plants compared to the control. Results from the field study demonstrated that only Dermacor-X-100® seed treatment resulted in significantly lower numbers of holes per plant compared to other treatments. Results from this study indicate that Dermacor-X-100® seed treatment could be used as a valuable component of an integrated pest management program for sugarcane borer in Louisiana rice. As the larval boring behavior, life cycle and injury caused by *E. loftini* and *D. saccharalis* are generally similar, and because chlorantraniliprole, the active ingredient in Dermacor-X-100®, is highly effective against lepidopterans (Lahm et al. 2009), our results for *D. saccharalis* may extend to *E. loftini* and may contribute to management of this stem boring species as well. Way et al. (2009) also evaluated Dermacor-X-100® seed treatment for control of rice water weevil and the stem borer complex in rice in Texas (*E. loftini* and *D. saccharalis*). Although whitehead (discolored panicles with empty or partially filled grains) densities were not high in untreated plots in their study, the highest rate of Dermacor-X-100® (0.1 mg a.i per seed) seed treatment provided complete control. The seed treatment rates of Dermacor-X-100® used in the present study (0.3-0.9 mg a.i per seed) were lower than the highest rate used in Way et al. (2009).

Insecticides are the primary control tactic used to manage pests of rice, and worldwide use was estimated at \$910 million in 1988 (Woodburn 1990) and \$1.14 billion in 1996 (International Rice Research Institute World Rice Statistics). According to Chelliah & Bharathi (1994) chemical control is the only means of suppressing stem borers rapidly and economically. Two pyrethroid insecticides (lambda-cyhalothrin and gamma cyhalothrin) are currently labeled for stem borer control in Louisiana rice (LSU Agcenter 2013). Stem borers are difficult to control with foliar insecticides even when applied at high rates at regular intervals over the growth of the crop (Litsinger et al. 2006) because the feeding habits of stem borers shelter them from non-systemic insecticides and thereby reduce their effectiveness (Litsinger et al. 2005). The lack of economic thresholds for stem borers in rice makes it difficult to decide when to treat and sometimes leads to multiple applications. Moreover, foliar sprays targeted at eggs and larvae also come in contact with natural enemies of stem borers, and secondary outbreaks have been reported

in areas with heavy insecticide usage (Pathak & Khan 1994). Reay-Jones et al. (2007) concluded that pyrethroids applied twice during the rice reproductive phase caused the greatest decrease in whiteheads and yield losses. However, the effects of insecticide applications on yield losses were highly variable. In the present study, none of the foliar insecticides used in the field study resulted in significant reduction in plant injury caused by *D. saccharalis*, probably because their application was badly timed. In the case of pyrethroids, applications may have been made too late, after significant infestation of larvae has already occurred. In the case of neonicotinoids, failure probably resulted from too late application.

The use of systemic insecticides, including systemic seed treatments like Dermacor-X-100®, avoid many of the problems associated with use of foliar insecticides against stem borers. Seed treatments are easily applied and economically justified as they require smaller amounts of active ingredient. Moreover, effective seed treatments reduce the number of aerial application of insecticides and this leads to reduction in both expenses and environmental disruption. Pathak (1971) and Aquino & Pathak (1976) reported that granular formulations of systemic insecticides were more effective than conventional foliar insecticides for stem borer control.

In the present study, there were no differences in mortalities of larvae feeding on plants treated with different seed treatment rates (i.e., larval mortality was not rate dependent). Similar activities of chlorantraniliprole at different seed treatment rates (rate independence) have been reported for larval forms of rice water weevils feeding on roots of rice plants (Lanka et al. 2014). In the latter study, concentrations of chlorantraniliprole in rice shoots did not increase linearly with seed treatment rates and most of the active ingredient was confined in the roots. The absence of differences in larval survival of borers on plants treated with different rates of Dermacor could be due to the limited systemic movement of chlorantraniliprole in shoots combined with the high larvicidal potency of chlorantraniliprole. Further studies are required to quantify Dermacor-X-100® levels in the shoots of late-season rice and relate these levels to larval mortality.

With the increasing impact of stem borers on rice in the southeastern United States, there is an urgent need to develop management strategies for stem borers that incorporate all relevant tactics. Greater sustainability in integrated pest management programs is often achieved by balanced use of different control tactics (Luckmann & Metcalf 1994). In previous studies, oviposition preference and larval performance of sugarcane borers were found to differ on 8 cultivars of rice grown widely in Louisiana (Hamm et al. 2011; Sidhu et al. 2013 unpublished). In another

study, silicon (Si) incorporation into soil led to an increase in levels of Si in plant tissues and reduced performance of *D. saccharalis* larvae in rice plants (Sidhu et al. 2013). Therefore, combined use of Dermacor-X-100® seed treatments along with resistant cultivars and Si soil amendment may form the basis of a more sustainable management program for borer populations on an areawide basis. Combined use of these tactics has the potential to reduce the cost and number of insecticide applications in rice. Moreover, because Dermacor-X-100® provides high levels of protection against rice water weevil, the major pest of U.S. rice, use of Dermacor-X-100® has the potential to protect rice from multiple pests. Future research should focus on studying the integration of Dermacor-X-100® seed treatments with cultivar resistance and cultural controls, especially soil silicon amendment, against the entire pest complex in U.S. rice.

ACKNOWLEDGMENTS

The authors would like to thank Drs. Bill Williams and Srinivas Lanka for their assistance in field and greenhouse studies. Approved for publication by the Director of the Louisiana Agricultural Experiment Station as manuscript number 2013-234-9571.

REFERENCES CITED

- AQUINO, G. B., AND PATHAK, M. D. 1976. Enhanced absorption and persistence of carbofuran and chlordimeform in rice plant on root zone application under flooded conditions. *J. Econ. Entomol.* 69: 686-690.
- IRRI (INTERNATIONAL RICE RESEARCH INSTITUTE). 1996. World rice statistics. International Rice Research Institute, Manila, Philippines.
- BLANCHE, B., HARRELL, D., AND SAICHUK, J. 2009. General agronomic guidelines, pp. 3-15 *In* J Saichuk [ed.], Louisiana Rice Production Handbook. LSU Agcenter Publ. 2321, LSU Agcenter, Baton Rouge, LA, USA.
- BOWLING, C. C. 1967. Insect pests of rice in the United States, pp. 551-570 *In* IRRI [eds.], The major insect pests of the rice plant. Proc. Symp. Intl. Rice Research Inst. Johns Hopkins University Press, Baltimore, MD.
- BROWNING, H. W., WAY, M. O., AND DREES, B. M. 1989. Managing the Mexican rice borer in Texas. *Texas Agric. Exp. Stn.* B-1620.
- BUTT, B. A., AND CANTU, E. 1962. Sex determination of lepidopterous pupae. USDA, Agricultural Research Service Report 33-75. 7 pp.
- CASTRO, B. A., RILEY, T. J., LEONARD, B. R. AND J. BALDWIN. 2004. Borers Galore: Emerging Pests in Louisiana Corn, Grain Sorghum and Rice. *Louisiana Agric.* 46: 4-7.
- CHELLIAH, S. AND BHARATHI, M. 1994. Insecticide management in rice pp. 657-680 *In* E. A. Heinrichs [ed.], Biology and Management of Rice Insects, Wiley, New York.
- CORDOVA, D., BENNER, E. A., SACHER, M. D., RAUH, J. J., SOPA, J. S., AND LAHM, G. P. 2006. Anthranilic di-amides: a new class of insecticides with a novel mode of action, ryanodine receptor activation. *Pestic. Biochem. Physio.* 184: 196-214.
- CORDOVA, D., BENNER, E. A., SACHER, M. D., RAUH, J. J., SOPA, J. S., AND LAHM, G. P. 2007. Elucidation of the mode of action of Rynaxypyr, a selective ryanodine receptor activator, pp. 121-126 *In* H. Ohkawa, H. Miyagawa and P. W. Lee [eds.], Pesticide Chemistry, Crop Protection, Public Health, and Environmental Safety. Wiley-VCH, Weinheim, Germany.
- DOUGLAS, W. A., AND INGRAM, J. W. 1942. Rice-field insects. USDA. Circ. 632: 1-32.
- DUPONT™ 2011. Reduced rate for use as a seed treatment on dry seeded rice for control of rice water weevil in the states of Arkansas, Louisiana, Mississippi and Missouri. EPA Reg. No. 352-820.
- HAMM, J. C., SIDHU, J. K., STOUT, M. J., HUMMEL, N. A., AND REAGAN, T. E. 2011. Oviposition behavior of *Diatraea saccharalis* (Lepidoptera: Crambidae) on different rice cultivars in Louisiana. *Environ. Entomol.* 41(3):571-577
- HOLLOWAY, T. E., HALEY, W. E., LOFTIN, U. C., AND HEINRICH, C. 1928. The sugarcane-borer in the United States. USDA Tech. Bull. 41: 77.
- HUMMEL, N. A., HARDY, T., REAGAN, T. E., POLLET, D. K., CARLTON, C. E., STOUT, M. J., BEUZELIN, J. M., AKBAR, W., AND WHITE, W. H. 2010. Monitoring and first discovery of the Mexican rice borer *Eoreuma loftini* (Lepidoptera: Crambidae) in Louisiana. *Florida Entomol.* 93: 123-124.
- JOHNSON, K. J. R. 1984. Identification of *Eoreuma loftini* (Dyar) (Lepidoptera:Pyralidae) in Texas, 1980: Forerunner for other sugarcane boring pest immigrants from Mexico? *Bull. Entomol. Soc. America* 30: 47-52.
- LAHM, G. P., CORDOVA, D., AND BARRY, J. D. 2009. New and selective ryanodine receptor activators for insect control. *Bioorg. Med. Chem.* 17: 4127-4133.
- LANKA, S. K., OTTEA, J. A., BEUZELIN, J. M., AND STOUT, M. J. 2012 Effects of chlorantraniliprole and thiamethoxam rice seed treatments on egg numbers and first instar survival of *Lissorhoptus oryzophilus* (Coleoptera: Curculionidae). *J. Econ. Entomol.* 106(1): 181-188.
- LANKA, S. K., STOUT, M. J., BEUZELIN, J. M., AND OTTEA, J. A. 2013. Activity of chlorantraniliprole and thiamethoxam seed treatments on life stages of the rice water weevil as affected by distribution of insecticides in rice plants. *Pest Mgt. Sci.* 70: 338-344.
- LITSINGER, J. A., BANDONG, J. P., CANAPI, B. L., DELA CRUZ, C. G., PANTUA, P. C., ALVIOLA, A. L., AND BATAY-AN, E. H. 2005. Evaluation of action thresholds for chronic rice insect pests in the Philippines. I. Less frequently occurring pests and overall assessment. *Intl. J. Pest Mgt.* 51: 45-61.
- LITSINGER, J. A., BANDONG, J. P., CANAPI, B. L., DELA CRUZ, C. G., PANTUA, P. C., ALVIOLA, A. L., AND BATAY-AN, E. H. 2006. Evaluation of action thresholds against chronic insect pests of rice in the Philippines: IV. Stemborers. *Intl. J. Pest Mgt.* 52: 194-207.
- LUCKMANN, W. H., AND METCALF, R. L. 1994. The pest management concept , pp. 1-34 *In* R. L. Metcalf and W. H. Luckmann [eds.], Introduction to Insect Pest Management. Wiley, New York, USA.
- MARTINEZ, A. J., BARD, J., AND HOLLER, T. A. 1988. Mass rearing sugarcane borer and Mexican rice borer for production of parasites *Allorhogas pyralo-*

- phagus* and *Rhacontus rosilensis*. U.S. Department of Agriculture-APHIS-PPQ, APHIS 83-1.
- OLIVER, B. F., GIFFORD, J. R., AND TRAHAN, G. F. 1972. Differential infestation of rice lines by the rice stalk borer. *J. Econ. Entomol.* 62: 711-713.
- PATHAK, M. D. 1971. Resistance to insect pests in rice varieties. *Oryza* 8, 135-144.
- PATHAK, M. D., AND KHAN, Z. 1994. Insect pests of rice. Intl. Research Institute, Los Banos, Philippines and Intl. Centre for Insect Physiology, Nairobi, Kenya. 89 pp.
- REAY-JONES, F. P. F., WILSON, L. T., REAGAN, T. E., LEGENDRE, B. L., AND WAY, M. O. 2008. Predicting Economic Losses from the Continued Spread of the Mexican Rice Borer (Lepidoptera: Crambidae). *J. Econ. Entomol.* 101(2): 237-250.
- REAY-JONES, F. P. F., WAY, M. O., AND REAGAN, T. E. 2007. Economic assessment of controlling stem borers (Lepidoptera: Crambidae) with insecticides in Texas rice. *Crop Prot.* 26: 963-970.
- REAY-JONES, F. P. F., WAY, M. O., AND REAGAN, T. E. 2007a. Economic assessment of controlling stem borers (Lepidoptera: Crambidae) with insecticides in Texas rice. *Crop Prot.* 26: 963-970.
- REAY-JONES, F. P. F., REAGAN, T. E., WAY, M. O., AND LEGENDRE, B. L. 2005. Concepts of areawide management of the Mexican rice borer (Lepidoptera: Crambidae). *Sugar Cane Intl.* 23: 20-24.
- REAY-JONES, F. P. F., AKBAR, W., AND REAGAN, T. E. 2005a. Mexican rice borer control, 2004. *Arthropod Mgt. Tests* 30: F81.
- ROE, R. M., HAMMOND, A. M., REAGAN, T. E., AND HENSELEY, S. D. 1981. A bibliography of the sugarcane borer *Diatraea saccharalis* (Fabricius), 1887-1980. *USDA Agric. Res. Serv., Agric. Rev. Man., Southern Series* 20: 1-2.
- SAS INSTITUTE. 1999. User's manual, version 8.0. SAS Institute, Cary, NC
- SIDHU, J. K., STOUT, M. J., AND BLOUIN, D. C. 2013. Performance and preference of sugarcane borer, *Diatraea saccharalis*, on different rice cultivars. *Entomologia Experimentalis et Applicata* 103(6):656-664.
- TUKEY, J. W. 1953. The problem of multiple comparisons. Department of Statistics, Princeton University, Princeton, NJ.
- VERGARA, B. S. 2001. Rice plant growth and development, pp. 13-22 *In* B. S. Luh, [ed.], *Rice Production*, vol. I. Van Nostrand Reinhold, New York, USA,
- WAY, M. O. 1990. Insect pest management in rice in the United States, pp. 210-222 *In* B. T. Grayson, M. B. Green and L. G. Copping [eds.], *Pest Management in Rice*. Elsevier Applied Science, New York, USA,
- WAY, M. O., NUNEZ, M. S., AND PEARSON, R. A. 2009. Insecticidal seed treatments and conservation tillage. *Proc. 12th Ann. National Conservation Systems Cotton & Rice Conf.* Cotton Incorporated.
- WAY, M. O. 2003. Rice Arthropod pests and their management in the United States, pp. 437-456 *In* C. W. Smith and R. H. Dilday [eds.], *Rice: Origin, History, Technology, and Production*. John Wiley & Sons, Inc., Hoboken, NJ.
- WAY, M. O., AND ESPINO, L. 2010. Insect management, pp. 37-51. *In* M. O. Way [ed.], *Texas rice production guidelines*. Texas AgriLife Research and Extension Center at Beaumont, Beaumont, TX.
- WAY, M. O., REAY-JONES, F. P. F., AND REAGAN, T. E. 2006. Resistance to stem borers (Lepidoptera: Crambidae) among Texas rice cultivars. *J. Econ. Entomol.* 99: 1867-1876.
- WOODBURN, A. T. 1990. The current rice agrochemicals market, pp. 15-30 *In* B. T. Grayson, M. B. Green, and L. G. Copping [eds.], *Pest Management in Rice*, Elsevier Applied Science, New York, USA.