Management of Stemborers (Lepidoptera: Crambidae) Using Foliar-Applied Chlorantraniliprole in Rice

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Management of stemborers (Lepidoptera: Crambidae) using foliar-applied chlorantraniliprole in rice

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Abstract

Rice is one of the most important crops in Louisiana and Texas, USA. It is subjected to various insect pests throughout the growing season. Lepidopteran stem-boring pests including the Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), are increasing in economic importance as insect pests in rice production, particularly in southwest Louisiana, USA. Field trials were conducted in Louisiana and Texas to examine the efficacy of foliar-applied insecticides (chlorantraniliprole and the pyrethroids ζ-cypermethrin and λ-cyhalothrin) and chlorantraniliprole seed treatment for control of rice stemborers during 2018 and 2019. Furthermore, a diet incorporation assay assessed the toxicity of chlorantraniliprole to laboratory-reared *E. loftini*. Results of field experiments in Louisiana showed foliar applications of chlorantraniliprole, at 22 to 35 d after permanent flood was established, reduced stemborer injury to rice by 57.9 to 96.5% in 2018 and 73.9 to 87.5% in 2019 compared to nontreated or pyrethroid-treated field plots. However, rice yields in 2019 did not vary among insecticide-treated and nontreated plots. In the Texas field experiments, chlorantraniliprole applied as seed treatment reduced stemborer injury, but was not effective in reducing injury when sprayed directly to soil after planting or when applied at permanent flood. The LC_{50} and LC_{90} (lethal concentration that produced 50% and 90% mortality, respectively) of chlorantraniliprole on third-instar *E. loftini* were 0.09 ± 0.03 and 0.53 ± 0.17 µg a.i. mL^{-1}, respectively, at 6 d after exposure. At 10 d after exposure, LC_{50} and LC_{90} were 0.04 ± 0.02 and 0.16 ± 0.04 µg a.i. mL^{-1}, respectively. In addition to chlorantraniliprole seed treatment, foliar application of chlorantraniliprole in rice could provide a new tool for management of damaging stemborer infestations.

Key Words: chemical control; diamide toxicity; *Eoreuma loftini*; Mexican rice borer

Resumen

El arroz es uno de los cultivos más importantes de Louisiana y Texas, EE. UU. Está sujeto a varias plagas de insectos durante la temporada de crecimiento. Las plagas de lepidópteros que perforan los tallos, incluido el barrenador mexicano del arroz, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), están aumentando en importancia económica como plagas de insectos en la producción de arroz, particularmente en el suroeste de Louisiana, EE. UU. Se realizaron ensayos de campo en Louisiana y Texas para examinar la eficacia de los insecticidas de aplicación foliar (clorantraniliprol y los piretroides ζ-cipermetrina y λ-cihalotrina) y el tratamiento de semillas de clorantraniliprol para el control de barrenadores del tallo del arroz durante el 2018 y 2019. Además, un ensayo de incorporación a la dieta evaluó la toxicidad del clorantraniliprol para *E. loftini* criado en laboratorio. Los resultados de los experimentos de campo en Louisiana mostraron que las aplicaciones foliares de clorantraniliprol, de 22 a 35 días después de que se estableció la inundación permanente, redujeron el daño del barrenador del tallo al arroz en un 57,9 a 96,5% en el 2018 y de 73,9 a 87,5% en el 2019 en comparación con las parcelas del campo no tratadas o tratadas con piretroides. Sin embargo, los rendimientos de arroz en el 2019 no variaron entre parcelas tratadas con insecticida y no tratadas. En los experimentos de campo de Texas, el clorantraniliprol aplicado como tratamiento de semillas redujo el daño del barrenador del tallo, pero no fue efectivo para reducir el daño cuando se roció directamente al suelo después de plantar o cuando se aplicó en inundaciones permanentes. La CL50 y CL90 (concentración letal que produjo 50% y 90% de mortalidad, respectivamente) de clorantraniliprol en *E. loftini* de tercer estadio fueron 0,09 ± 0,03 and 0,53 ± 0,17 µg i.a. mL^{-1}, respectivamente, a los 6 días después de la exposición. A los 10 días después de la exposición, la CL50 y la CL90 fueron 0,04 ± 0,02 y 0,16 ± 0,04 µg i.a. mL^{-1}, respectivamente. Además del tratamiento de semillas con clorantraniliprol, la aplicación foliar de clorantraniliprol en el arroz podría proporcionar una nueva herramienta para el manejo de infestaciones dañinas de barrenadores del tallo.

Palabras Clave: control químico; toxicidad por diamida; *Eoreuma loftini*; barrenador mexicano del arroz

Rice, *Oryza sativa* L. (Poaceae), is one of the most important crops globally, and is consumed by more than half of the world's population (Mohanty 2013). The US is a major rice producer with an hectarage of 1.1 M ha in 2019, of which 172,000 ha of rice were planted in Louisiana, USA, and 64,000 ha in Texas, USA (USDA ERS 2020). The complex of lepidopteran stem-boring insect pests (Lepidoptera: Crambidae) attacking rice in the southern US includes the Mexican rice borer, *Eoreuma loftini* (Dyar); the sugarcane borer, *Diatraea saccharalis* F.; and the rice stalk borer, *Chilo plejadellus* (Zincken) (all Lepidoptera: Crambidae) (Way 2003; Beuzelin et al. 2016). Stemborer larvae feed on the leaf sheath for a few d before boring into the stem. When feeding occurs during the vegetative stage of plant development, the affected tillers wither and die, a condition known as a deadheart (Pathak & Khan 1994). When feeding occurs at reproductive stages of plant development, injury prevents panicle development. Panicles may emerge, but remain straight, are whitish, and do not produce grains, a condition known as a whitehead (Pathak & Khan 1994). Stemborer activity in the field commonly is measured by determining the density of whiteheads,

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which is negatively associated with rice yield (Way et al. 2006; Reay-Jones et al. 2007a).

Stemborers are becoming increasingly problematic in southwestern Louisiana rice paddies, particularly the invasive *E. loftini*. This pest was detected in Texas in 1980 on sugar cane in the Lower Rio Grande Valley, and has since spread northeast through the rice production area along the Texas Gulf Coast (Johnson & van Leerdam 1981; Reay-Jones et al. 2007b). *Eoreuma loftini* first was detected in southwest Louisiana in Calcasieu Parish in 2008 (Hummel et al. 2010) and was recorded infesting rice in 7 Louisiana parishes by 2013 (Wilson et al. 2015). This invasive pest has become firmly established in the state's rice production area, as indicated by continued expansion and high population density in many regions (Wilson et al. 2017a). At present, *E. loftini* is a consistent pest of rice in southwest Louisiana and Texas, where it is responsible for high densities of whiteheads in unprotected rice fields (Wilson et al. 2015; Way & Pearson 2017a,b, 2019). Continuous expansion of *E. loftini* in Louisiana rice is predicted to cause economic losses exceeding US $40 million annually if infestations are not managed (Reay-Jones et al. 2008a).

Chemical control is an important component of stemborer management in rice. In fact, effective control of stemborer infestations in US rice currently solely relies on insecticides. Prior to 2010, control of stemborers in Texas rice was accomplished with foliar applications of pyrethroid insecticides (ζ-cypermethrin and λ-cyhalothrin) (Reay-Jones et al. 2007a). The use of insect growth regulators tebufenozide and novaluron effectively controls *D. saccharalis* and *E. loftini* in sugar cane (Beuzelin et al. 2010; Wilson et al. 2012, 2017b) but are less economical than pyrethroids when used in rice (Castro et al. 2005; Reay-Jones et al. 2007a). Pyrethroids are not widely used for stemborers in Louisiana because foliar applications of these insecticides can have negative effects on crawfish, *Procambarus* spp. (Decapoda: Cambaridae), which often is produced in rotation with rice in the state (Barbee & Stout 2009). Economic thresholds for stemborer management in rice have not been developed, and the decision to apply insecticides ultimately is based on producer experience and perceived levels of stemborer infestations (Beuzelin et al. 2016). Thus, effectively timing insecticide applications is challenging, and control with pyrethroids is inconsistent. Stemborer control is now achieved commonly with chlorantraniliprole seed treatments that are applied primarily for rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) (Hummel et al. 2014; Wilson et al. 2019). These treatments are prophylactic and cannot be applied to control stemborer infestations that arise during the growing season. More control options are needed as damaging stemborer infestations become more prevalent. The efficacy of foliar applications of diamides, particularly chlorantraniliprole, has not been evaluated in rice.

This study evaluated the efficacy of chlorantraniliprole (foliar applications and seed treatment) and pyrethroids at multiple application times for stemborer control under field conditions. Furthermore, the toxicity of chlorantraniliprole on laboratory-reared *E. loftini* was assessed via a diet-incorporated insecticide assay.

Materials and Methods

LOUISIANA FIELD EXPERIMENTS

The efficacy of foliar-applied insecticides to control stemborer infestations in rice was evaluated in 3 small-plot field experiments under natural infestation levels at the Louisiana State University Agricultural Center, H. Rouse Caffey Rice Research Station (30.24184°N, 92.34568°E) in Crowley, Louisiana from 2018 to 2019. Seeds of medium-grain rice variety 'Caffey' were planted in 2018, and the Clearfield long-grain rice variety 'CL153' was sown in 2019. In both yr, seeds were drill-seeded in 1.5 m W × 7 m L plots at a rate of 79 kg ha^{-1}. Field plots were surface irrigated as necessary to facilitate plant emergence. Rice plots were maintained in accordance with fertilization and weed control practices recommended for commercial production in Louisiana (Saichuk 2014). The experimental design in both yr was a randomized block design with 4 (2018) or 5 (2019) blocks and 1 replicate per block. In 2018, 4 insecticide treatments and a non-treated control were assigned randomly to field plots (20 plots total). Foliar applications of 3 rates of chlorantraniliprole (Prevathon®, FMC Corporation, Philadelphia, Pennsylvania, USA) at 38.0, 53.0, and 75.0 g a.i. ha^{-1}, and 1 rate of ζ-cypermethrin (Mustang Maxx®, FMC Corporation, Philadelphia, Pennsylvania, USA) at 28.0 g a.i. ha^{-1} were made at 35 d after permanent flood (13 Jul 2018) when rice plants were at the maximum tillering developmental stage. The presence of *E. loftini* larvae feeding in leaf sheaths at the time of application was confirmed prior to insecticide application. Several plants exhibiting stemborer feeding injury were examined by peeling the leaf sheaths and pulling out the stemborer larvae. In 2019, the field was divided into 2 separate sections, where 25 plots received insecticide treatment at 22 d after permanent flood (25 Jul 2019) whereas the other 25 plots received treatment at 33 d after permanent flood (5 Aug 2019). Foliar applications of 3 rates of chlorantraniliprole at 38.0, 53.0, and 67.0 g a.i. ha^{-1}, and 1 rate of λ-cyhalothrin (Warrior®, Syngenta Crop Protection, Greensboro, North Carolina, USA) at 14.0 g a.i. ha^{-1} were made at each application time. All insecticide treatments were applied using a CO_2-pressurized backpack sprayer (R & D Sprayers, Opelousas, Louisiana, USA) calibrated to deliver 94 liters ha^{-1}. The sprayer was equipped with 2 TeeJet TP11001 nozzles at 48 cm spacing. Stemborer injury was assessed by recording the total number of whiteheads in each plot at 100% heading. Whiteheads were not collected in 2018 but approximately 50 whiteheads from each trial in 2019 were brought back to the laboratory and dissected to identify the stemborer species. At grain maturity, entire plots were harvested using a small-plot combine (Wintersteiger Delta Plot Combine, Wintersteiger Inc., Salt Lake City, Utah, USA) and grain weights were adjusted to 12% moisture (Saichuk 2014) to estimate yields in 2019. Rice field plots were not harvested in 2018.

TEXAS FIELD EXPERIMENTS

Field experiments were conducted at Texas A&M AgriLife Research Center (30.07747°N, 94.29453°E) at Beaumont, Texas, and at the David R. Wintermann Rice Research Station (29.58954°N, 96.33124°E) at Eagle Lake, Texas, in 2019. For both locations, seeds of long-grain rice variety 'Presidio' were drill-seeded at a rate of 90 kg ha^{-1}. Plots were 1 m W × 5.5 m L in Beaumont and 1.5 m W × 5 m L in Eagle Lake. Rice plots were surface irrigated as necessary to facilitate plant emergence, and permanent flood was applied approximately 4 wk after planting. Plots were maintained following recommendations for rice production in Texas (Way et al. 2014). The experimental design for both locations was a randomized block design with 4 blocks and 1 replicate per block. In Eagle Lake, 4 insecticide treatments and a non-treated control were randomized to plots (20 plots total). Foliar applications of chlorantraniliprole at 75.0 g a.i. ha^{-1}, ζ-cypermethrin at 28.0 g a.i. ha^{-1}, and λ-cyhalothrin at 18.7 g a.i. ha^{-1} were made at permanent flood on 13 May 2019 consistent with recommended timing for insecticide applications targeting *L. oryzophilus* (Espino & Way 2014). In addition to foliar application, chlorantraniliprole was applied as a seed treatment (Dermacor® X-100, Corteva Agriscience, Wilmington, Delaware, USA) at a rate of 75.0 g a.i. ha^{-1}. In Beaumont, 4 insecticide treatments and a non-treated control were randomly assigned to plots (20 plots total). Foliar applications of 3 rates of chlorantraniliprole (38.0, 53.0, and 75.0 g a.i. ha^{-1}) were made at permanent flood on 10 Jul 2019 and 1 rate of chlorantraniliprole (75.0 g a.i. ha^{-1}) was applied to soil at planting on 15 Jun 2019. All foliar applications were done using a CO_2-pressurized backpack sprayer (R & D Sprayers, Opelousas, Louisiana, USA) equipped with 3 TeeJet TP800067 nozzles and was calibrated to deliver 252.6 liters ha^{-1}. Stemborer injury was assessed by recording the total number of whiteheads in 4 middle rows per plot when rice plants reached 100% heading. In Eagle Lake, rice plants were allowed to regrow (ratoon) after harvest. Stemborer injury was assessed in ratoon rice as previously described. All whiteheads were collected and subsequently dissected to identify the stemborer species.

LABORATORY BIOASSAY

Eoreuma loftini larvae used in this assay were obtained from a colony maintained continuously at Louisiana State University Agricultural Center, Department of Entomology, Baton Rouge, Louisiana, USA. The *E. loftini* colony originated from larvae collected in rice fields at the H. Rouse Caffey Rice Research Station in 2018. Larvae were reared on artificial diet (Southland Products, Lake Village, Arkansas, USA) in 30 mL clear portion containers (Conex® Complements™, Dart Container Corporation, Mason, Michigan, USA) until pupation. Pupae were collected and sexed following the methods of Butt and Cantu (1962). Equal numbers of male and female pupae were placed in 3L plastic containers (Prolon®, Cambro Manufacturing Co., Huntington Beach, California, USA) with rolled germination papers (Anchor Seed Solutions 38#, Anchor Paper Co., St. Paul, Minnesota, USA) as substrate for oviposition. Upon eclosion, adults were provided with a 1:1 mixture of honey and beer (Miller Lite, Molson Coors, Milwaukee, Wisconsin, USA) and distilled water as source of food. Eggs were collected and left to hatch in an 8-cell plastic tray (BIO-SMRT-8, C-D International, Allentown, New Jersey, USA) with a moistened cotton ball in each cell. The colony was maintained at 28 ± 2 °C, 30% relative humidity, and a 14:10 h (L:D) photoperiod.

Mortality of *E. loftini* from chlorantraniliprole was evaluated using a diet-incorporated insecticide bioassay according to methods of Akbar et al. (2008). Chlorantraniliprole (Prevathon®, FMC Corporation, Philadelphia, Pennsylvania, USA) was dissolved in distilled water to create a stock solution of 200 µg a.i. mL^{-1}. Serial dilutions to achieve 8 diet concentrations (0.05, 0.1, 0.3, 0.5, 0.8, 1.0, 1.5, 2.0 µg a.i. mL^{-1}) and a non-treated control (distilled water only) were created to yield 200 mL of diet per concentration. Diet was poured into each 30 mL clear portion cup at 5 mL of diet per cup and left to solidify for 1 h. Third-instar larvae (about 13 mg) were starved for 3 h and placed individually in each cup on the surface of the diet. A total of 270 larvae (30 larvae per concentration) were used for the assay. Insect mortality was evaluated at 6, 10, and 12 d after exposure. Mortality was defined as lack of movement after stimulation with a camel-hair paintbrush.

STATISTICAL ANALYSES

All analyses were performed in SAS version 9.4 (SAS Inc., Cary, North Carolina, USA). Whitehead density and yield data (2019) from the 3 Louisiana field experiments and the Beaumont experiment were analyzed separately using generalized linear mixed models (PROC GLIMMIX) with insecticide treatment as a fixed effect and block as a random effect. Whitehead data from the Eagle Lake field experiment were analyzed with insecticide treatment, crop type (main crop or ratoon crop), and insecticide × crop type as fixed effects, and block as a random effect using generalized linear mixed models (PROC GLIMMIX). To ensure normality and homogeneity of variances, residuals were examined after each analysis (PROC UNIVARIATE). Whitehead data from Beaumont and Eagle Lake were square root transformed prior to analysis but untransformed means and standard errors are presented. The analyses were modelled using the Gaussian distribution. The Kenward-Roger adjustment was used to calculate error degrees of freedom and Tukey's HSD post hoc analysis ($\alpha = 0.05$) was used for all mean separations.

Mortality data from the laboratory bioassay were analyzed with log-dose probit analysis (PROC PROBIT) to determine concentrations that produced 50 and 90% mortality (LC_{50} and LC_{90}). Data were not corrected for control mortality since all larvae placed on non-treated diet survived.

Results

LOUISIANA FIELD EXPERIMENTS

All recovered stemborer larvae were identified as *E. loftini*. Whitehead densities were reduced by 57.9 to 96.5% in insecticide-treated plots compared to untreated control plots in 2018 ($F = 14.70$; df = 4, 11; $P < 0.001$) (Fig. 1A). The greatest control was achieved

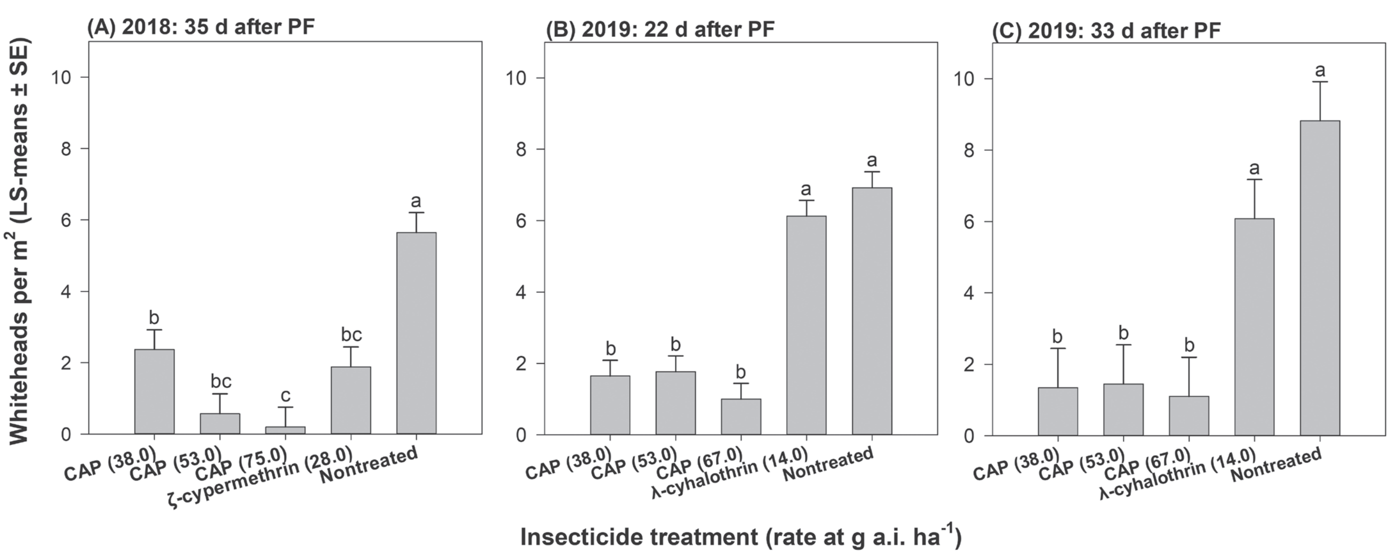

Fig. 1. Whitehead density as affected by insecticide treatment applied 35 d (2018) and 22 and 33 d (2019) after permanent flood (PF) was established, Crowley, Louisiana, USA. CAP = chlorantraniliprole. Bars within graphs accompanied by the same letter do not differ significantly (P > 0.05, Tukey's HSD).

in plots treated with chlorantraniliprole at 53.0 and 75.0 g a.i. ha^{-1}, where whitehead densities were reduced by 89.5% and 96.5%, respectively, compared to the control (Fig. 1A). In 2019, chlorantraniliprole reduced the number of whiteheads per m^2 by 73.9 to 85.7% compared to the untreated control and λ-cyhalothrin when applied 22 d after permanent flood (F = 49.95; df = 4, 16; P < 0.001) and 85.2 to 87.5% when applied 33 d after permanent flood (F = 11.40; df = 4, 16; P < 0.001). Plots sprayed with λ-cyhalothrin at 22 and 33 d after permanent flood had 11.5 and 31.4% less whiteheads, respectively, compared to the control but the differences were not statistically significant. Different rates of chlorantraniliprole were similarly effective in reducing stemborer injury at both application timings (Fig. 1B, C). There were no differences in yields among plots treated with insecticides and non-treated plots when applications were made 22 d (F = 0.97; df = 4, 16; P = 0.449) or 33 d (F = 0.5; df = 4, 16; P = 0.736) after permanent flood (Fig. 2).

TEXAS FIELD EXPERIMENTS

All stemborer larvae recovered from whiteheads collected at Beaumont and at Eagle Lake were *E. loftini*. In Beaumont, foliar applications of chlorantraniliprole at planting and at permanent flood did not affect whitehead density (F = 1.76; df = 4, 15; P = 0.189) (Fig. 3). At Eagle Lake, significant reductions of 34.1 to 39.3% in whitehead densities were observed in plots in which rice seeds were treated with chlorantraniliprole compared to plots treated with foliar applications of pyrethroids, chlorantraniliprole, and untreated control (F = 4.64; df = 4, 27; P = 0.006) (Fig. 4A). Furthermore, whitehead density was 58.9% higher in the ratoon crop compared to the main crop (F = 37.10; df = 1, 27; P < 0.001) (Fig. 4B). There was no interaction detected between insecticide treatment and crop type (F = 0.98; df = 4, 27; P = 0.437).

LABORATORY BIOASSAY

Larval mortality at 10 and 12 d after exposure was the same; thus, mortality data at 12 d after exposure are not presented. Chlorantraniliprole resulted in 80% mortality of third-instar *E. loftini* at the end of 6 d and 91.3% at 10 d after exposure across all concentrations. The LC_{50} and LC_{90} at 6 d after exposure were 0.09 ± 0.03 and 0.53 ± 0.17 S.E. µg a.i. mL^{-1}, respectively (χ^2 = 50.36; P < 0.001) (Fig. 5A). At 10 d after exposure, the LC_{50} and LC_{90} were 0.04 ± 0.02 and 0.16 ± 0.04 S.E. µg a.i. mL^{-1}, respectively (χ^2 = 23.84; P < 0.001) (Fig. 5B).

Discussion

The results from this study indicate that foliar application of chlorantraniliprole at maximum tillering (e.g., 22–35 d after permanent flood) provides effective control of *E. loftini* infestations in rice. Consistent with prior studies, chlorantraniliprole seed treatments are effective against stemborers, particularly *D. saccharalis* and *E. loftini* (Sidhu et al. 2014; Wilson et al. 2015; Villegas et al. 2017, 2019). Our results indicate that the efficacy of foliar chlorantraniliprole applications is similar to seed treatments when timed properly. Seed treatment of rice with chlorantraniliprole resulted in up to 85% reduction in stemborer injury (Way & Pearson 2014). Foliar application of chlorantraniliprole in sugar cane substantially reduced damage by *E. loftini* and *D. saccharalis* compared to insect growth regulators (Wilson et al. 2017b). Our results indicate that chlorantraniliprole will provide improved control of stemborers compared to pyrethroids, which are currently registered for use in rice production. However, these results are based only on plot research and should be tested at the field scale.

Foliar application of ζ-cypermethrin in the Louisiana field experiments in 2018 provided adequate control of stemborer injury. The application of ζ-cypermethrin was done after field scouting revealed stemborer larvae

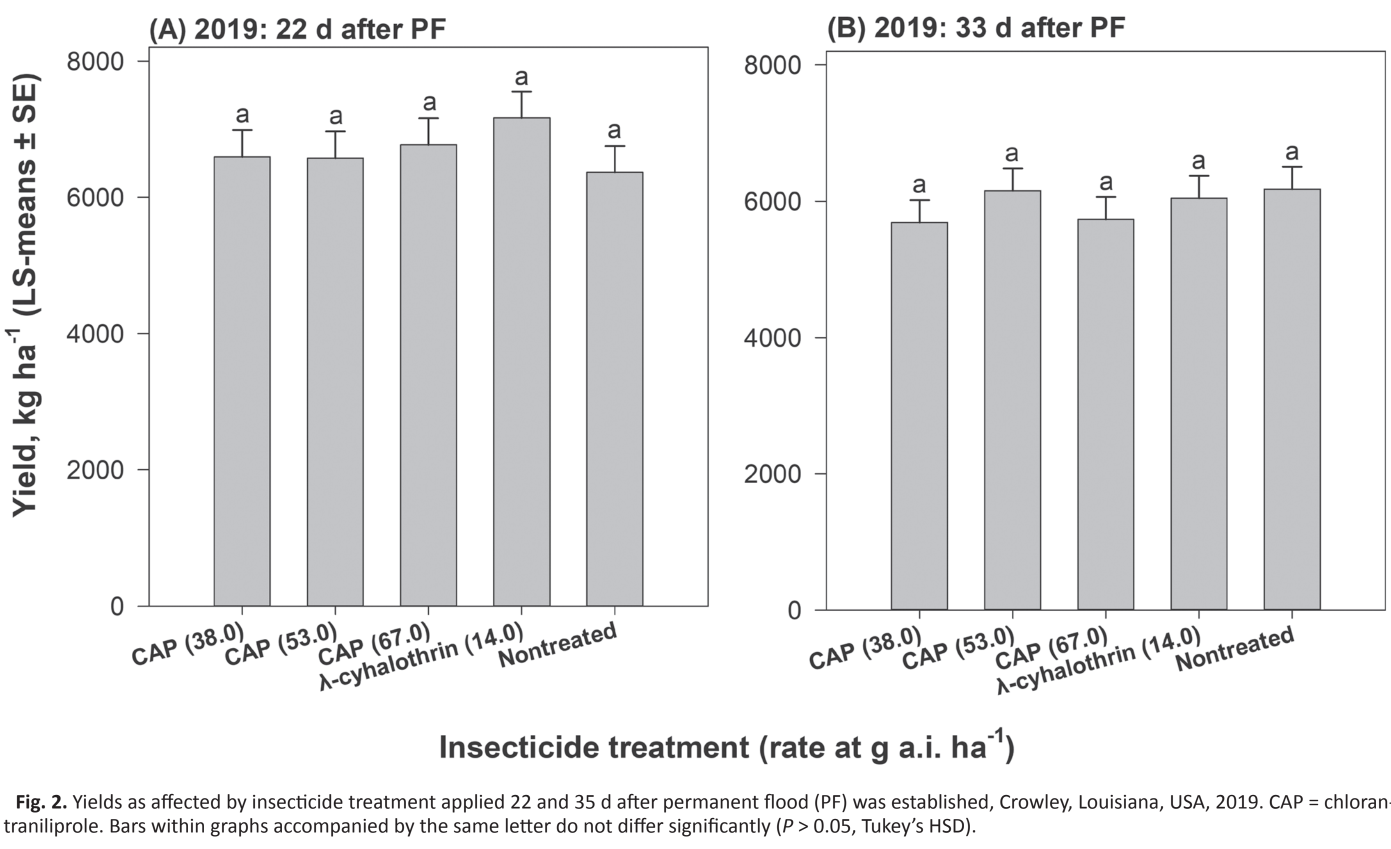

Fig. 2. Yields as affected by insecticide treatment applied 22 and 35 d after permanent flood (PF) was established, Crowley, Louisiana, USA, 2019. CAP = chlorantraniliprole. Bars within graphs accompanied by the same letter do not differ significantly (P > 0.05, Tukey's HSD).

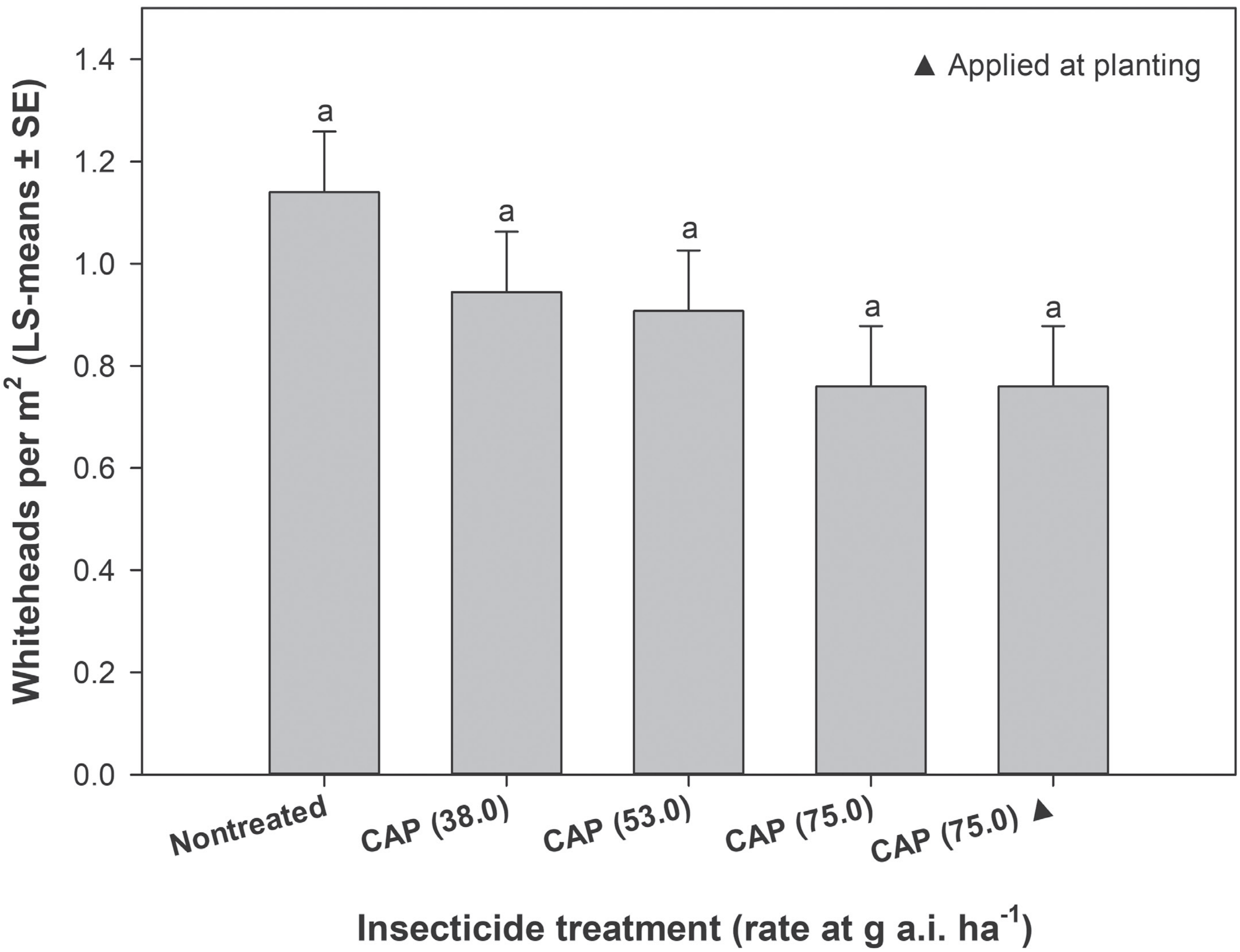

Fig. 3. Whitehead density as affected by insecticide treatment, Beaumont, Texas, USA, 2019. The ▲ symbol following an insecticide treatment designates chlorantraniliprole that was applied at planting. The remainder of the treatments were applied at permanent flood. Bars within graphs accompanied by the same letter do not differ significantly ($P > 0.05$, Tukey's HSD).

were present in rice leaf sheaths. However, scouting was not conducted prior to spraying in 2019, and failure of λ-cyhalothrin to provide control may have been the result of early application timing rather than low toxicity of the active ingredient to the stemborers. The longer residual activity and high potency of chlorantraniliprole on stemborers may allow for more flexibility in the timing of applications. However, results from the Texas field experiments revealed that applications before or at permanent flood for *L. oryzophilus* control are too early to be effective in reducing stemborer injury. Application timing is critical for pyrethroids because these compounds have high contact toxicity, but low residual activity (Athanassion et al. 2004). Short residual activity of pyrethroids, β-cyfluthrin in particular, also has been attributed to ineffective control of *E. loftini* in sugar cane (Wilson et al. 2012). Scouting for stemborer larvae starting when rice plants undergo panicle differentiation through to the boot stage is recommended to confirm pest presence prior to making foliar insecticide applications (Espino & Way 2014). Prior to seed treatments, pyrethroids applied twice during the reproductive stages of rice reduced whiteheads and yield losses; however, effects of insecticide applications on yield losses were variable (Reay-Jones et al. 2007a).

Superior efficacy of chlorantraniliprole against lepidopteran stemborers is due to its high toxicity, as well as its systemic and residual activity compared to other insecticides (Villegas et al. 2019). Chlorantraniliprole belongs to a relatively new class of insecticides known as anthranilic diamides and is highly selective towards ryanodine receptors that are critical for muscle contraction in insects (Cordova et al. 2006; Lahm et al. 2007, 2009). This chemistry also offers improved application in integrated pest management programs. Chlorantraniliprole is more selective to target insects than pyrethroids, which have been shown to have negative effects on natural enemies and beneficial parasitoids (Douglas & Tooker 2016). Previous studies also have reported that chlorantraniliprole has demonstrated low toxicity to beneficial parasitoid wasps, including egg parasitoids from the genus *Trichogramma* (Hymenoptera: Trichogrammatidae) which are recognized globally for their role in controlling lepidopteran pest species (de Freitas-Bueno et al. 2008; Brugger et al. 2010). Chlorantraniliprole has limited non-target effects on crawfish, an important attribute for insecticides used in Louisiana rice production (Barbee et al. 2010). This is crucial because in southwest Louisiana, where the majority of rice is produced in the state, rice and crawfish are often cultured together, or in proximity to each other.

The absence of economic thresholds for *E. loftini* makes it difficult for producers to make an informed decision on when to apply insecti-

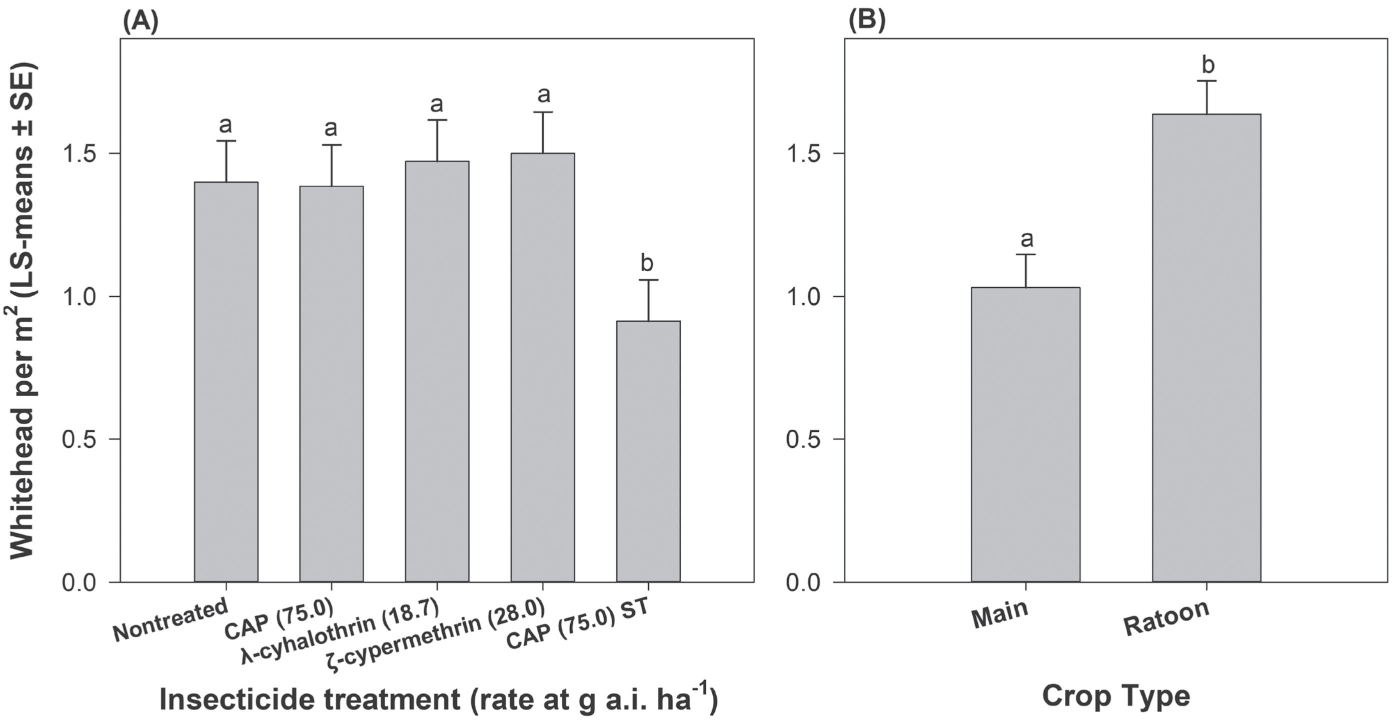

Fig. 4. Whitehead density as affected by insecticide treatment (A) and crop type (B), Eagle Lake, Texas, USA, 2019. ST = for seed treatment, whereas CAP = chlorantraniliprole. Except for seed treatment, the remainder of the treatments were applied at permanent flood. Bars within graphs accompanied by the same letter do not differ significantly ($P > 0.05$, Tukey's HSD).

cides. Although insecticidal seed treatments are available, they generally are applied in anticipation of high pest pressure, thus treatment is done before any pests are observed. Furthermore, neonicotinoid seed treatments are not effective in reducing stemborer injury (Way & Pearson 2017a, 2017b; Wilson et al. 2018). Future research on *E. loftini* should focus on developing thresholds for foliar applications and refining scouting strategies to mitigate damaging infestations of *E. loftini* in rice, including the use of chlorantraniliprole in integrated pest management programs.

Development of an economic threshold has been hindered by unclear impacts of stemborer injury on rice yields. Despite substantial reduction of *E. loftini* injury in chlorantraniliprole-treated plots in the Louisiana field experiments, there was no impact on rice yields. Yield response to insecticide applications may have been masked by infestations of *L. oryzophilus* across treatments. Unmanaged *L. oryzophilus* infestations can cause 20 to 30% yield reductions (Reay-Jones et al. 2008b). The impact of *E. loftini* on rice yields is not well established. Nonetheless, Reay-Jones et al. (2007a) reported a 2.3% reduction in yields for each whitehead per m^2 caused by mixed infestations of *D. saccharalis* and *E. loftini.* Results from field trials conducted by Wilson et al. (2021) in Louisiana that controlled for *L. oryzophilus* infestations have attributed 14% yield reductions or 1.6% yield loss per whitehead per m^2 due to *E. loftini* infestations in late-planted rice.

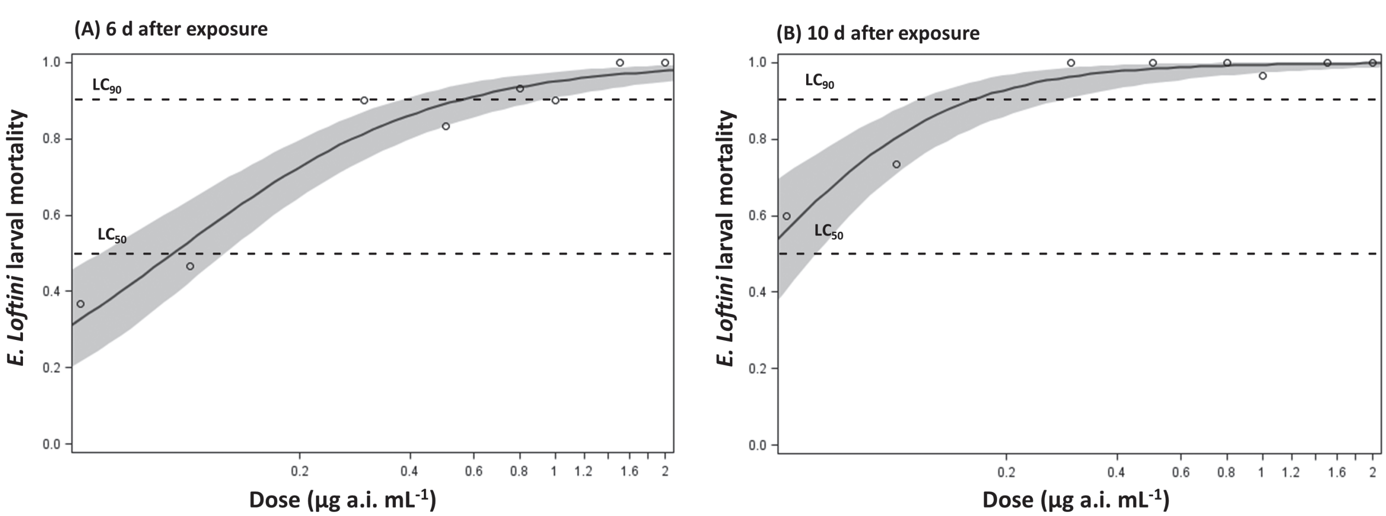

Fig. 5. Dose-mortality responses of *Eoreuma loftini* larval mortality with 95% confidence limits (shaded area) 6 and 10 d after exposure. Dashed line represents 50 and 90% mortality (LC_{50} and LC_{90}).

Ratoon rice, or a second crop developing from the main crop, may be more vulnerable to stemborer injury as indicated by high whitehead densities in ratoon rice compared to the main crop observed in this study. The failure to detect interactions between crop type and insecticide applications on whitehead density indicates that chlorantraniliprole seed treatment provided similar control in both main and ratoon crops. This finding further demonstrates the exceptional systemic activity of seed-applied chlorantraniliprole that remained active against *E. loftini* 168 d after planting. However, it is important to recognize that although the systemic activity of chlorantraniliprole may provide benefits to ratoon rice, this could have other implications not measured by this study.

This study provides the first baseline toxicity data for *E. loftini* that can be used for future resistance monitoring, especially considering that chlorantraniliprole is used widely to control *E. loftini* in both rice and sugar cane (Wilson et al. 2015, 2017b). In China, several field populations of Asiatic rice borer, *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae), have developed moderate to high levels of resistance to chlorantraniliprole (Mao et al. 2019). To our knowledge, there have been no reports of resistance of *E. loftini* or *D. saccharalis* to chlorantraniliprole in the US. Toxicity (LC_{50}) of chlorantraniliprole to *E. loftini* reported in this study is consistent with a previous study on other lepidopteran pests (Lepidoptera: Noctuidae) that reported LC_{50} values ranging from 0.02 to 0.09 μg a.i. mL^{-1} for fall armyworm, *Spodoptera frugiperda* (J.E. Smith); corn earworm, *Helicoverpa zea* (Boddie); and tobacco budworm, *Heliothis virescens* F. (all Lepidoptera: Noctuidae) (Temple et al. 2009). Villegas et al. (2019) also reported high toxicity of chlorantraniliprole to *D. saccharalis* indicated by high larval mortality in rice treated with reduced rates of chlorantraniliprole.

Foliar application of chlorantraniliprole is not currently labeled for use in rice in the US, but EPA registration is being sought. Registration of chlorantraniliprole for foliar application in rice will provide an additional tool for control of damaging stemborer infestations in Louisiana and Texas.

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