MISSISSIPPI SOYBEAN PROMOTION BOARD

# Insect Management Strategies using Insect Growth Regulators in Mississippi Soybean

By

Sawyer Clayton Hopkins

To be Approved by:

Whitney D. Crow (Co-Major Professor)
Donald R. Cook (Co-Major Professor)
Jefferey Gore
Angus L. Catchot Jr.
Natraj Krishnan (Graduate Coordinator)
Scott T. Willard (Dean, College of Agriculture and Life Sciences)

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Name: Sawyer Clayton Hopkins

Date of Degree: May 10, 2024

Institution: Mississippi State University

Major Field: Agricultural Life Science

Major Professors: Whitney D. Crow and Donald R. Cook

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Soybean looper and corn earworm are economically damaging pests in Mississippi soybeans. Chemical control plays a large role in the control of these pests. Some producers have started applying an automatic co-application of insecticide and fungicide at the R3 growth stage. Insect growth regulators are a commonly used insecticide for this management strategy. The purpose of this research was to evaluate the impact of insect growth regulators on soybean looper and corn earworm mortality when applied with an automatic fungicide application at the R3 growth stage in soybean. Insecticide treatments included methoxyfenozide, diflubenzuron, and novaluron.  These insect growth regulators showed very little control and mortality, especially when compared to Chlorantraniliprole, which has become an industry standard for control of lepidopteran pest control of in soybean. The automatic application of an insect growth regulator insecticide with a fungicide at the R3 growth was not viable for economic insect management strategies.

# DEDICATION

I would like to dedicate this thesis to my loving wife, Jordan, and parents, Houston, and Gina, without them, none of this would have been possible. Thank you for encouraging, sacrificing, and supporting me to achieve a higher education.

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# CHAPTER I

## Review of Literature

### 1.1 Soybean

Soybean, *Glycine max* (L.) Merr., is an economically important crop in the United States. During 2022 and 2023, the United States planted over 69 million hectares of soybeans (USDA 2022). In 2022, the soybean crop had its largest production year since 1924, with an economical value of over $61 billion (USDA 2022). The United States is currently the world's second largest producer of soybeans behind Brazil, while Mississippi ranks 12$^{th}$ in U.S. production.

Soybean is classified as a short-day plant, meaning reproduction is initiated by longer periods of darkness (Owens et al. 2012). This allows for production across broad geographies and environments. Soybeans have ten maturity groups 00-VIII, each separated by daylength to initiate flowering (the first stage of reproduction). The lower the maturity group number, the longer the day needed to initiate flowering (Owens et al. 2012). During the summer months, daylength increases going north, and as a result 00-III are considered northern maturity groups, while IV-VIII are southern maturity groups (Owens et al. 2012). Planting maturity groups not adapted for a specific geographical region will likely result in poor yield and or a failed crop (Owens et al. 2012). Soybean varieties may have either an indeterminate or determinate growth pattern. Indeterminate varieties (groups 00-IV) continue vegetative growth after the initiation of flowering, whereas determinate varieties (groups V-VIII) do not not continue vegetative growth once flowering has begun. Historically, most of the varieties grown in the southern United States were determinate varieties (Stowe and Vann 2022). In Mississippi, it is most common to see maturity group IV and V varieties. Historically, soybeans planted in the Midsouth were maturity groups V-VIII and were typically planted during May and June. Maturity groups V-VIII are known for their excessive water needs during the reproductive stages, which typically coincides with drought and extreme temperatures (Heatherly et al. 1998). Due to environmental stress, those maturity groups are not able to reach their full potential and yields are greatly impacted. This led many producers to switch from the traditional soybean system to the early planted soybean system (ESPS) (Heatherly et al. 1998). This involves planting early maturing indeterminate varieties, commonly maturity group IV in the Midsouth, in April to minimize heat and moisture stress to the plants during the important reproductive stages (Heatherly et al. 1998). During some years, the ESPS is not an option for growers due to various factors such as field conditions being too wet to prevent early planting. Another more common reason for later planted soybeans is fields that are set up in a double crop wheat-soybean production system. This system implements a two-crop approach, utilizing a fall and spring crop, however the wheat is not ready for harvest at the time when ESPS soybeans are planted.

## 1.2 Soybean Looper

Soybean looper, *Chrysodeixis includens* (Walker), is a lepidopteran pest in the Noctuidae family. Found throughout most of North and South America, soybean looper is known to feed on 174 different plant species (Carter and Gillet-Kaufman 2020). Although it has a broad range of hosts, the preferred host of this pest is soybean (Carter and Gillet-Kaufman 2020). Soybean looper causes indirect damage to the soybean crop through larvae feeding on foliage. When left untreated, soybean looper can defoliate large amounts of foliage. Most of the soybean looper infestations in the United States are found in the southeastern part of the country, but they can range from Texas to Maine (Carter and Gillet-Kaufman 2020). Most soybean looper populations in the United States migrate from Central and South America, as these areas are the most common overwintering sites. Some populations may overwinter in the most southern regions of the United States in some years (Carter and Gillet-Kaufman 2022).

Soybean loopers can have multiple generations within a growing season. Soybean looper does not have a diapause mechanism, therefore they must migrate into the U.S. every year from areas where it is warm enough for them to reproduce year-round. Soybean looper females lay eggs individually and prefer the underside of the leaf in the upper two-thirds of the crop canopy and oviposit an average of 650 eggs (Jost and Pitre 2002). Once an egg is laid the larva usually hatches in approximately three days. Nearly all soybean loopers complete their larval development within six instars (Shour and Sparks 1981).

Identification of a soybean looper is important because there are numerous defoliating pests of soybean and other crops, however soybean looper has distinct features. The soybean looper egg is a typical noctuid egg with a small round greenish-white appearance. Larvae are typically light green with a longitudinal white strip that runs parallel down the body on both sides (Shour and Sparks 1981, Brown 2012). Larvae also appear thicker in the rear and taper down towards the head and can reach a maximum length of around 3.3 cm (Carter and Gillet-Kaufman 2020). Adult moths appear gray to black with an average wingspan of 3.5 cm. When looking at a soybean looper from above, the hindwings may appear to have a lighter color than the forewings, additionally a white figure eight can be seen in the middle of the forewings (Smith 1994, Brown 2012).

### 1.3 Soybean Looper Feeding in Soybean

Soybean looper is the third most damaging insect pest in soybean behind the stink-bug complex and corn earworm (Musser et al. 2023). This makes soybean looper the number one defoliating insect of soybean. During 2022, the soybean looper was responsible for 19.1% of total costs and losses of the Mississippi soybean crop, which equated to $43,921,131 (Musser et al. 2022) In Mississippi, soybean loopers typically arrive during late August to September (Catchot et al. 2015). Soybean loopers feed in the canopy, starting from the lower regions, and working up and outward toward the top of the plant (Hodgson et al. 2021). This feeding pattern is very distinct to looper species and as Hodgson et al. describes "gives the leaf a 'windowpane' effect". A single larva can eat up to 114 $cm^2$ with the highest consumption occurring during the fifth and sixth instars (Hodgson et al. 2021).

Soybean looper thresholds in Mississippi are different prior to bloom and after bloom. The threshold prior to bloom is 35% defoliation with larvae present and drops to 20% defoliation with larvae present after bloom (Crow et al. 2023). Vegetative stage soybean can tolerate higher defoliation levels without yield loss since the plants aren't putting energy into seed development at this time (Owens et al. 2012). Even with some foliage loss, plants are still able to carry out daily functions required for development. However, after bloom, the plant becomes more sensitive to defoliation by impacting the energy put into seed development. Therefore, if left uncontrolled it will likely have a direct impact on yield.

Defoliation may affect the soybean plant in a wide array of ways including reduced transpiration, reduced photosynthesis, and lowering the ability to compensate for water loss, nutrient deficiencies, and other external factors that may reduce yields (Owens et. al 2012). In addition to direct yield losses, defoliation can lead to iron chlorosis further reducing yields (Fehr et al. 1985). Owens et. al (2012) observed soybeans that experienced defoliation levels greater than 57% from R3 to R5 yielded less than soybeans that experienced the same levels of defoliation at R6. Soybean defoliation can not only reduce yields, but in some cases where there is extreme defoliation, seed quality can be compromised (Weber 1955). Seed quality can be comprised by a reduction in size or decrease in oil content, both effects of defoliation.

## 1.4 Soybean Looper Management Practices

The soybean looper is one of the more difficult pests to manage in soybeans. The feeding pattern of soybean looper often creates challenges with proper insecticide coverage because oviposition and early larval development occurs in the lower canopy. Insecticide resistance in soybean looper has been a problem in the southern US since the 1960's, which creates another set of challenges for producers (Brown 2012). Pyrethroid, carbamate, organophosphate, and diamide insecticides are commonly used in many pest management programs, however the control is inconsistent. Resistance to pyrethroid, organophosphate, and carbamate insecticides decreases the number of effective options with different modes of action. The most used pesticides against soybean looper include: chlorantraniliprole, methoxyfenozide, spinetoram, or some combination of insecticides (Crow et al. 2023). Early planting date is the most effective management practice for soybean looper, but chemical control becomes important once populations are established in a soybean field. Insecticide applications are warranted when defoliation percent or populations are above threshold. Natural insect predators can combine with other biological control agents such as entomopathogenic fungi and viruses to suppress soybean looper populations (Brown 2012). Some common disease agents that aid in control of soybean loopers include *Entomophthora gammae* (Weiser), *Metarhizium rileyi* (Farlow), and several species of *Massospora* especially in cotton-soybean production systems (Burleigh 1972, Beach and Todd 1986, Brown 2012). Soybean loopers are also prone to a nucleopolyhedrovirus (NPV) especially under cool and rainy conditions (Rice 2022). Occasionally, a disease outbreak can naturally suppress populations and prevent any insecticide applications. Depending on pest prevalence, natural predators may suppress the population enough to avoid chemical control. Common predators of soybean looper larvae include big-eyed bugs, *Geocoris bullatus* (Say) and *Geocoris punctipes* (Say), spined soldier bug, *Podisus maculiventris* (Say), minute pirate bug, *Orius insidiosus* (Say), numerous *Nabis* species, as well as multiple species of ladybird beetles (Carter and Gillet-Kaufman 2020). The most effective control measure of soybean insect pests is having an early planted soybean production system, ESPS, which may avoid the window of susceptibility.

## 1.5 Corn Earworm

Corn earworm, *Helicoverpa zea* (Boddie), is an economically damaging pest of many North American crops. It has numerous common names including soybean podworm, bollworm, tomato fruitworm, and sorghum headworm. Its preferred host is silking corn, but corn earworm infests a wide variety of host plants. This pest can be found on 16 different crops and a wide variety of weedy hosts; in Mississippi, corn earworm are commonly found in corn, cotton, and soybean (Barber 1937, Neunzig 1963, Davidson and Peairs 1966, Matthews 1991, Swenson et al. 2014). Corn earworm is distributed throughout the Americas, and occurs year-around near the equator (Hardwick 1965, Swenson et al. 2014). In the southern United States, first generation adults emerge from the soil in early spring and feed on non-cultivated hosts (Capinera 2001, Swenson et al. 2014). Second generation eggs are often laid on corn silks for a couple reasons, corn ears provide protection and food (Reisig 2020). With readily available food and protection, corn earworm populations increase greatly from the first to second generation due to more accessible food and better climatic conditions (Reisig 2020). During midsummer each corn earworm generation completes its lifecycle in about a month (Quaintance 1905, Swenson et al. 2014). Once larvae have completed their development on the corn ear, they feed their way out of the ear falling to the ground to pupate in the soil. Following pupation, moths emerge and seek other hosts, including cotton, grain sorghum, peanut, and soybean and numerous non-cultivated hosts (Reisig 2020). As a result, these later generation larvae feed on numerous crops and wild hosts. Identification of this pest is important because there are many caterpillar larvae that feed on soybean (Musser et al. 2022). Larvae vary in color from light green to pink, rust, or dark brown with pale longitudinal stripes running the entire length of the body. The larvae have orange to yellow head capsules with black legs and can reach a length of 50-mm during the last larval stage (Neunzig 1964). Adults can reach up to 25-mm long and are tan in color, and wing markings include a wavy band along the wing edge with a dark brown spot in the center of the forewings (Towles 2020).

### 1.6 Corn Earworm Feeding in Soybean

Corn earworm is the second most economically damaging insect pest in the Mississippi soybean production system. Behind the stink bug complex, corn earworm is the number one damaging lepidopteran pest in the state’s soybeans (Musser et al. 2022). During 2022, corn earworm infested 70% of Mississippi soybean acreage and accounted for 29% of the state’s total losses plus costs. This economic value equaled $66,581,662 lost for Mississippi soybean producers (Musser et al. 2022). Corn earworm is both a direct and indirect pest of soybean, meaning they feed directly on the pods, and also feed on other plant structures such as the leaves. Small larvae prefer to feed on soybean blooms when available, but when not available, feed on leaves or pods (Mueller and Engroff 1980, Swenson et. al 2014, Adams 2016). During the R3-R4 growth stage, damage per larva can be most severe due to an abundance of small pods with immature seeds, as compared to damage from feeding during the R5-R6 growth stage, become more pods are usually developed (McWilliams 1983, Swenson et al. 2013, Adams 2016). Damage during the later growth stages reduces the ability of the plant to compensate, and as a result yield can be reduced (Thomas et al. 1974, McPherson and Moss 1989, Adams 2016).

## 1.7 Corn Earworm Management Practices

Treatment of corn earworm should be focused on targeting $2^{nd}$-$4^{th}$ instar larvae. As $1^{st}$ instar larvae are typically hard to find in protected areas within the plants, and $5^{th}$ and $6^{th}$ instar larvae have already caused economic damage and are preparing to pupate (Reisig 2020). Fields should be monitored weekly to detect population emergence or increases especially during reproductive stages when populations tend to move into the field. This pest can be difficult to sample when using the sweep net method, therefore supplemental visual sampling may be needed on blooms and pods. (Crow et. al 2023). Before bloom, plants should be treated when leaf defoliation levels are 35% or higher. However, after bloom when using a drop cloth, the threshold is 1 to 1.5 larvae per row foot. A study conducted in 2015, evaluated the threshold of corn earworm in determinate and indeterminate soybeans, and findings lead the author to recommend an action threshold of 3.5 corn earworm larvae per row-m when looking at indeterminate soybeans (Adams 2015). When using a sweep net after bloom, the threshold is nine larvae per twenty-five sweeps. Corn earworms may be more difficult to sample with a sweep net, therefore it is important to sweep deep into the canopy with extra force (Crow et al. 2023). Growers have several products to select from, however, the most common insecticides are chlorantraniliprole, chlorantraniliprole plus lambda-cyhalothrin, methoxyfenozide, and methoxyfenozide plus spinetoram. (Stewart 2019). Heligen, an NPV virus, can be beneficial for corn earworm control but proper application timing is critical for effective control (Villegas 2023).

### 1.8 Insect Growth Regulators

Insect growth regulators (IGR) are a type of insecticide used for pest management in numerous crops. Insect growth regulators mimic hormones involved with development, molting, and metamorphosis preventing the insect from continuing through development, which ultimately leads to insect death. There are three types of insect growth regulators which includes a chitin synthesis inhibitor, juvenile hormone analogs and mimics, and anti-juvenile hormone agents (Krysan and Dunley 1993). Each of these IGRs have a different mode of action that ultimately results in interrupting normal insect growth and reproduction (Krysan and Dunley 1993). Common insect growth regulators are diflubenzuron, novaluron, and methoxyfenozide. While these types of insecticides are effective, they are sometimes tank mixed with other insecticides to increase mortality and effectiveness. Increased adoption of these products is due to their relatively low cost compared to other products, low acute toxicity to humans, and low toxicity to off target species. Additionally, they tend to be selective and less harmful to the environment as compared to broad spectrum insecticides (Krysan and Dunley 1993).

Automatic co-applications of multiple pesticides in agriculture has become a controversial topic throughout the years. One of the benefits of a co-application is the ability to target multiple pests with one application. Yet, the most beneficial aspects of a co-application are time saving by decreasing the number of trips across the field, subsequently decreasing input cost. While co-applications can be beneficial, they are often met with backlash from the negative effects of this management strategy. The biggest issue with co-applying is the increased potential for prophylactic applications. This is often the situation with fungicide by insecticide co-applications in soybean. Automatic fungicide applications in Mississippi soybean at R3-R4 have been a common practice over the past decade and have benefited producers greatly (Allen and Irby 2018). However, co-application of these fungicide treatments with an insecticide has been controversial. In many situations, a co-application including an insecticide is generally not needed due to the lack of insect infestations. One way to reduce pesticide applications is to avoid co-applications below threshold, and wait until populations build and thresholds are met (Lorenz 2018). Every decision made involving insecticide applications should be based on lowering the risk of a negative environmental and economic impact (Catchot et. al 2018). When fungicide timings and threshold levels of insect pests occur, co-applications are extremely effective in saving money for producers. The largest insect associated economic loss to US soybeans in 2022 was automatic insecticides (Musser et al. 2022). Reiterating the fact that co-applications of a fungicide and insecticide can be cost efficient when done correctly.

## 1.9 Objective

As previously discussed, both soybean loopers and corn earworm are major pests of soybean, especially when an ESPS is not available. With increasing input costs and insect resistance, many traditional products for these pests are not working, so many producers are looking at new control options. As a result, over the last decade it has been common to see a fungicide and insecticide (typically an Insect Growth Regulator) co-application at the R3-R4 growth stage in soybeans. Therefore, studies were implemented to evaluate the impacts of various insect growth regulators on soybean looper and corn earworm infestations, mortality, and their impacts on soybean yield compared to control with a diamide insecticide.

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# CHAPTER II

## Residual Efficacy of Insect Growth Regulators against *Helicoverpa zea* (Boddie) and *Chrysodeixis includens* (Walker)

### 2.1 Abstract

In Mississippi, corn earworm, *Helicoverpa zea* (Boddie); and soybean looper, *Chrysodexis includens* (Walker), rank second and third respectively in economic costs plus losses in soybean production. Widespread adoption of the early soybean production system (ESPS) has been the most successful management strategy for Mississippi soybean producers in controlling these pests, because both corn earworm and soybean looper do not typically appear until later in the growing season. However, in some cases an ESPS is not plausible, and producers are forced to plant their crop later in the season. As a result, many producers have started using various insecticides to try and control infestations of these pests. The objective of this study was to examine the impact of insect growth regulators: methoxyfenozide (Intrepid 2F®; Corteva Agriscience, Indianapolis, IN), diflubenzuron (Dimilin® 2L; Chemtura Agrosolutions, Middlebury, CT), and novaluron (Diamond®; ADAMA, Raleigh, NC) on mortality of laboratory colonies of soybean looper and corn earworm in comparison to chlorantraniliprole (Prevathon®; FMC Corporation, Philadelphia, PA). Results showed that the insect growth regulator insecticides had low mortality on both pests, while chlorantraniliprole provided high initial mortality of soybean looper until it sharply declined after 7 days after treatment ; but showed good control on corn earworm out to 28 days after treatment.

## 2.2 Introduction

*Chrysodeixis includens* (Walker) and *Helicoverpa zea* (Boddie) are both lepidopteran pests of soybean. *Chrysodeixis includens* (Walker) is commonly referred to as the soybean looper while *Helicoverpa zea* (Boddie) has numerous common names, including cotton bollworm, soybean podworm, and corn earworm. This is due to the vast number of host plants, including nearly 16 cultivated crops and numerous wild hosts (Barber 1937, Neunzig 1963, Davidson and Peairs 1966, Matthews 1991, Swenson et al. 2013). Corn earworm and soybean looper rank second and third in economic damage to Mississippi soybean, behind the stink bug complex (Musser et al. 2022). While both feed in soybean, they also have different feeding patterns, one generally has an indirect impact on yield while the other has a direct impact. Corn earworms prefer flowers and soybean seeds, which decreases seed quality and quantity, but may still feed on leaves (Villegas 2023). Unlike corn earworm, the soybean looper is a defoliating caterpillar. Defoliation is described as the removal or loss of leaves, which can decrease yield indirectly (Owen 2012). Previous research indicates that defoliation before R3 and after R6 will not result in a substantial yield loss (Owen 2012). Defoliation during the early vegetative stages gives the plant more time to compensate for foliage loss (Weber 1955). However, all soybean types and varieties are vulnerable to yield loss from defoliation between R3-R6 (Dungun 1939, Fehr et al. 1981, Owen 2012). In 2022, soybean looper and corn earworm economical costs plus losses totaled just over $110.5 million (Musser et al. 2022). Therefore, monitoring of these pests is crucial to avoid detrimental effects to the crop. The threshold for soybean looper after bloom is nineteen larvae per twenty-five sweeps while corn earworm is less than half of that at nine larvae per twenty-five sweeps (Crow et al. 2023).

The best way to avoid late season infestations of soybean looper and corn earworm, like almost all soybean pests, is to have an early soybean production system (ESPS) (Carner et al. 1974, Poston et al. 2007, North 2019). Bateman et al. (2017) evaluated the impact of planting date on insect infestation in Mississippi soybeans. Earlier planted soybeans were at a less risk of soybean looper infestations than those planted later. Insecticide applications are a common management tool for both the soybean looper and corn earworm, with several insecticides having activity against both species. These include chlorantraniliprole, spinetoram, methoxyfenozide, novaluron and various combinations (Crow et al. 2023). Although chlorantriliprole has been inconsistent over the last few seasons against soybean looper, generally it has provided high efficacy on both soybean looper and corn earworm. Methoxyfenozide and novaluron show some control of soybean looper but marginal to low control of corn earworm (Crow et al. 2023).

Since the mid-2000's, an automatic foliar fungicide application to soybean during R3-R4 growth stages has become a common practice in Mississippi. This application is made for general foliar disease management and its perceived yield benefits (Wang et al. 2023). Due to the cost of chlorantraniliprole, and the inconsistency of other products some producers have started tank mixing an insecticide with an automatic fungicide application at the R3 growth stage (Catchot et al. 2018). Tank mixing an insecticide with an automatic fungicide spray shows potential to delay pest population build ups and potentially prevents an insecticide application later in the growing season. The peak of soybean looper infestation typically coincides with late planted soybeans entering the most vulnerable reproductive stages (Bateman et al. 2017). This can coincide with the automatic fungicide application timing in soybeans. Diflubenzuron has been used traditionally as a timing/automatic application because of its preventative characteristics and slow acting chemistry (Willrich et. al 2002). Diflubenzuron is effective against velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner), in numerous areas (Turnipseed et al. 1974 and Willrich et al. 2002). Many producers use cheaper products for this application, especially insect growth regulators like diflubenzuron. However, it has been documented that diflubenzuron has low mortality on soybean looper and corn earworm. Although diflubenzuron has low efficacy on the two major lepidopteran pests, some producers have continued to use this mixture to target other lepidopteran pests, with the hope of achieving some control against both corn earworm and soybean looper. Studies conducted in the early 2000's showed that preventative applications of methoxyfenozide kept soybean loopers below economic threshold when diflubenzuron proved ineffective (Willrich 2001). Applications made in the previous study were made in early August, when late planted soybeans were in the early reproductive stages, and soybean insect pest infestations levels were below threshold. Another insect growth regulator that has the potential to provide control was novaluron. Novaluron and diflubenzuron are similar in their mode of action, however in many cases novaluron provides better control on most lepidopteran pests (Crow et al. 2023).  Therefore, the objective of this study was to evaluate the residual efficacy and mortality of selected insecticides as potential candidates for co-application with fungicide at the R3-R4 growth stage for management of corn earworm and soybean looper.

## 2.3 Field Experiment Details

During 2022 and 2023, studies were conducted at the Delta Research and Extension Center in Stoneville, MS and at R.R Foil Research Station in Starkville, MS to determine the residual efficacy of selected insecticides against soybean looper and corn earworm. A randomized complete block design with four replications was utilized. Plots were four rows wide on 101.6cm row spacings and 12.19m in length in Stoneville, MS, while plots in Starkville, MS were four rows wide on 96.52 cm row spacings and 12.19 in length. Soybeans (Asgrow® 46XF2, Bayer CropScience, St. Louis, MO) were planted between late April and early May with a seeding rate 294,600 seed ha $^{-1}$. Treatments included chlorantraniliprole (Prevathon®; FMC Corporation, Philadelphia, PA) at 52 g ai ha$^{-1}$, methoxyfenozide (Intrepid 2F®; Corteva Agriscience, Indianapolis, IN) at 105 g ai ha$^{-1}$, diflubenzuron (Dimilin® 2L; Chemtura Agrosolutions, Middlebury, CT) at 70 g ai ha$^{-1}$, novaluron (Diamond®; ADAMA, Raleigh, NC) at 44g ai ha$^{-1}$, and an untreated control. All applications were made at approximately R1 growth stage to ensure enough foliage for bioassays. Applications were made with a Mudmaster (Bowman Manufacturing©, Newport, Arkansas) using Hollow TX-6 nozzles (TeeJet® Technologies, Glendale Heights, IL) at 93.5 L ha$^{-1}$ and 413kPa.

## 2.4 Insect Rearing

Insects, soybean looper and corn earworm, from colonies maintained at the Mississippi State University Insect Rearing facility were used for bioassays. The soybean looper colony was established from a field colony collected during 2013. The corn earworm colony was obtained from the United States Department of Agriculture (USDA) ARS in Stoneville, MS. This colony was established prior to 2011 and was supplemented with wild individuals during 2014 and 2023. The soybean looper colony was supplemented with wild individuals each year from 2017 through 2022. Colonies of both corn earworms and soybean loopers were maintained under 75-80% relative humidity, 14:10 light and dark photoperiods, and 26°C. After hatching, larvae were placed in 59.2 mL cups (Solo®, Dart Container Corp., Mason, MI), one per cup, which contained Tobacco Budworm Diet (Product #F9781B, Frontier Agricultural Sciences, Newark, DE). This diet also includes agar, vitamin mix, and propionic acid. Additionally, both insects were fed the same diet however linseed oil was added to diet for to soybean looper.

## 2.5 Soybean Leaf-Assays

Leaves were collected at 1,7,14,21, and 28 days after treatment (DAT). At each date, ten leaves per plot were removed from the middle two rows and placed into a 3785 mL plastic zip bag (Ziploc, S. C. Johnson & Son, Inc., Racine, WI). Crop growth stage was noted to unsure that the only leaves present at the time of application were collected and used in the study. To reduce contamination, leaves were collected using disposable gloves which were changed after leaves from all plots of a treatment had been collected. A 15 mm leaf disc was cut using a Brass Cork Borer (Eisco™, Rochester, NY) and individually placed into plastic 59.2 ml cups. To reduce contamination, all tools were washed or replaced between treatments.

Each cup was infested with a second instar larva (soybean looper or corn earworm). A plastic lid with agar, a clear solution to hold moisture in the cup, was placed on each cup to prevent the larva from escaping and to ensure the soybean leaf disc maintained adequate moisture. Three days after infestation, larvae were examined to determine mortality. A total of 10 cups per plot (treatment) was used and treatments were replicated four times. Both corn earworm and soybean looper bioassay tests were repeated four times each.

## 2.6 Data Analysis

Percentage mortality data for soybean looper and corn earworm were subjected to repeated measures analysis of variance with a generalized linear mixed model procedure (Proc Glimmix, SAS 9.4, SAS Institute Inc. Cary, NC). Mortality resulting from insecticides was corrected for control mortality using Abbott's formula and percent mortality was given a corrected value (Fleming and Retnakaran 1985). Treatment, days after treatment, and treatment by days after treatment were considered the fixed effects. While trial and replication nested within trial were considered random effects. Days after treatment was the repeated measure. The Kenward-Rogers method was used to calculate the degrees of freedom. The Least Square means were separated with Fisher's Protected LSD procedure with α set equal to 0.05. The means procedure was used to calculate means and standard errors of the means.

## 2.7 Results

An interaction between insecticide treatment and days after treatment was observed for soybean looper mortality ($F$=1.91; df=12,176.3; $P$=0.0355) (Table 2.1). At 1 DAT, chlorantraniliprole resulted in greater mortality than all other insecticides. For all insecticides, except diflubenzuron, higher mortality was observed at 1 DAT compared to any other sample date. For each insecticide, no differences in mortality were observed at 7 to 28 DAT. Diflubenzuron resulted in 23.1% mortality at 1 DAT. No differences in soybean looper mortality were observed for diflubenzuron across sample dates. Chlorantraniliprole resulted in a mortality of 86.4% at 1 DAT and provided >50% mortality on soybean looper out to 21 DAT. Methoxyfenozide resulted in 67.6% mortality at 1 DAT but < 25% at all other dates. The highest mortality observed with novaluron was 57.4% at 1 DAT, while all other sample dates observed mortality was < 30%. Diflubenzuron had < 25% mortality observed on all sample dates.

An interaction between insecticide treatments and days after treatment was also observed for corn earworm mortality ($F$=2.21; df=12,188.1; $P$=0.0127) (Table 2.2). Chlorantraniliprole resulted in greater mortality than methoxyfenozide, novaluron, or diflubenzuron at all sample dates. Chlorantraniliprole also resulted in > 87% mortality on all sample dates. Methoxyfenozide resulted in greater mortality of 75.9% at 1 DAT compared to all other sample dates with ≤ 56.4. The highest mortality observed with novaluron of 78.1% was observed at 7 DAT. Corn earworm mortality with novaluron was >60% at 1 and 21 DAT. Mortality was 59.2% at 14 DAT which was less than observed at 7 DAT. Diflubenzuron did not result in > 45% mortality on any sample date.

## 2.8 Discussion

None of the insecticides resulted in > 60% mortality of soybean looper after 1 DAT. Also, diflubenzuron did not result in > 25% at any sample date. Historically, chlorantraniliprole and methoxyfenozide have been used for soybean looper management. In the past, chlorantraniliprole has provided good control of soybean loopers out to 28 DAT. Recently performance has been erratic and/or less than satisfactory (Crow et al. 2023). Methoxyfenozide has been used against soybeans targeting soybean looper since 2006, but by 2008 control failures had already been reported (Brown 2012). Novaluron and diflubenzuron have not been considered adequately efficacious on soybean looper (Willrich 2002, Cook et al. 2022).

Chlorantraniliprole resulted in high corn earworm mortality up to 28 DAT in the current study and in others (Smith 2022). The effects of diflubenzuron resulted in low mortality, similar to that in a study conducted by Chandler et. al (1992). When looking at the effects of methoxyfenozide on corn earworm, one study observed that methoxyfenozide showed some control on corn earworm from 4 to 15 DAT (Akin et al. 2011). In the current study, methoxyfenozide resulted in > 32% mortality and novaluron resulted in >59% mortality out to 21 DAT.

The current study evaluated insecticides as candidates for the co-application with fungicides at the R3 growth stage of soybean. None of the insecticides resulted in ≥ 90% mortality of soybean looper on any sample date. Also, none of the insecticides resulted in > 60% mortality beyond 1 DAT. For corn earworm only, chlorantraniliprole resulted in > 85% mortality out to 28 DAT. For soybean looper, none of the insecticides resulted in high enough mortality to be candidates for this management strategy. For corn earworm, only chlorantraniliprole appeared to be promising. However, these studies were conducted with laboratory colonies of soybean looper and corn earworm, and performance against wild populations could be different.

Table 2.1 Impact of selected insecticides on second instar soybean looper larval mortality in leaf bioassays at 1,7,14,21, and 28 DAT during 2022 and 2023.

| | Mean (SEM) Soybean Looper Mortality[a] | | | | |
|---|---|---|---|---|---|
| Insecticide | 1 DAT[b] | 7 DAT | 14 DAT | 21 DAT | 28 DAT |
| Chlorantraniliprole | 86.4 (6.3)a | 52.3 (7.3)bc | 57.5 (9.1)bc | 54.0 (8.2)bc | 42.9 (8.0)cd |
| Methoxyfenozide | 67.6 (7.9)b | 21.4 (5.0)ef | 21.8 (3.1)ef | 18.8 (4.9)ef | 10.8 (4.4)f |
| Novaluron | 57.4 (6.4)bc | 28.3 (5.5)ef | 15.6 (6.7)ef | 15.8 (5.1)ef | 16.3 (4.5)ef |
| Diflubenzuron | 23.1 (5.1)ef | 22.9 (6.6)ef | 12.6 (3.9)ef | 12.3 (3.6)ef | 12.0 (4.5)ef |

Means followed by the same letter are not different according to Fishers Protected LSD test within an alpha of 0.05, ($F$=1.91; df=12,176.3; $P$=0.0355)
[a]Corrected for control mortality
[b]DAT represents the number of days after treatment was applied.

Table 2.2 Impact of selected insecticides on second instar corn earworm larval mortality in leaf bioassays at 1,7,14,21, and 28 DAT during 2022 and 2023.

| | Mean (SEM) Corn Earworm Mortality[a] | | | | |
|---|---|---|---|---|---|
| Insecticide | 1 DAT[b] | 7 DAT | 14 DAT | 21 DAT | 28 DAT |
| Chlorantraniliprole | 100 (0)a | 97.3 (1.5)a | 92.7 (4.1)ab | 88.6 (4.7)ab | 87.8 (5.3)ab |
| Methoxyfenozide | 75.9 (6.7)bcd | 56.4 (7.9)ef | 39.4 (9.7)fgh | 32.7 (8.7)ghi | 19.2 (4.7)i |
| Novaluron | 63.8 (7.9)cde | 78.1 (7.4)bc | 59.2 (10.3)def | 63.5 (9.8)cde | 45.5(5.9)fg |
| Diflubenzuron | 44.8 (8.7)fg | 38.2 (10.2)gh | 35.1 (9.8)ghi | 32.6 (8.1)ghi | 25.1 (7.8)hi |

Means followed by the same letter are not different according to Fishers Protected LSD test within an alpha of 0.05, ($F$=2.21; df=12,188.1; $P$=0.0127).
[a]Corrected for control mortality
[b]DAT represents the number of days after treatment was applied.

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# CHAPTER III

Evaluation of Insect Growth Regulators Co-applied with a Fungicide at the R3 Growth Stage in Soybean

## 3.1 Abstract

*Helicoverpa zea* (Boddie) and *Chrysodexis includens* (Walker) caused over $110,500,000 of combined costs plus losses to Mississippi soybean producers in 2023. Although pressure and damage can be variable from year to year, typically these pests are not prevalent in Mississippi soybean fields until later in the growing season. In late planted soybeans, it has become a common practice to add an insecticide to the automatic R3 fungicide application, and many producers use an insect growth regulator for this application. The objective of this study was to evaluate the impact of methoxyfenozide (Intrepid 2F®; Corteva Agriscience, Indianapolis, IN) diflubenzuron (Dimilin® 2L; Chemtura Agrosolutions, Middlebury, CT), novaluron (Diamond®; ADAMA, Raleigh, NC) when compared to chlorantraniliprole (Prevathon®; FMC Corporation, Philadelphia, PA) tank mixed with and without a fungicide to an untreated control. Results of all trials were similar. The management strategy of automatically applying a fungicide with an insecticide at R3, did not provide an economic benefit. In all trials, corn earworm pressure was absent, and while soybean looper pressure remained low in most situations; therefore, resulted in an unwarranted insecticide application. Even in high insect pressure, insecticide efficacy wasn't high enough to justify the additional cost.

## 3.2 Introduction

Soybean, *Glycine max* (L.) Merr., is Mississippi's top row-crop commodity, bringing in $1.8 billion dollars in 2022 (Coblentz 2022). Mississippi planted 934,824 hectares in 2022, while *Chrysodeixis includens* (Walker) infested 80% of fields planted, with 50% of those infested acres being above threshold and corn earworm, *Helicoverpa zea* (Boddie), infested 70% of all fields with 40% being above economic threshold. (Musser et al. 2022). Since the early 2000s, the increased adoption of early soybean production system (ESPS) has shifted planting forward to maximize yield potentials with fewer inputs (Thrash 2018). According to Bateman (2017), the optimum planting date to maximize yield in Mississippi is around April 20th. As a result, the crop can mature sooner and typically avoid late seasons pests like soybean looper and corn earworm. However, in years when environmental conditions are not favorable planting delays may occur leading to late-season insect management.

Corn earworm is a lepidopteran pest known to feed on multiple crops and wild hosts (King and Coleman 1989). This pest occurs in both North and South America between the latitudes of 40°N and 40°S (Adams 2015). In 2022, corn earworm caused the second most economic loss plus cost out of all the insect pests of Mississippi soybean (Musser et al. 2023). Corn earworms have multiple generations each year, each usually feeding on a different host. Cotton and soybean serve as the primary hosts for both third and fourth generation corn earworm (Jackson et. al 2008, Adams 2015). Over the last couple decades, shifts in crop production resulting in more soybeans and less cotton in Mississippi has caused an increase in soybean infestations by corn earworm (Adams 2015). Corn earworm larvae can reduce yield by defoliating leaves, delaying pod fill, and reducing the number of seeds per pod (Eckel et al. 1992). While leaf area reduction from defoliation can reduce yield, direct pod feeding causes the most economic loss from corn earworm damage (Eckel et al. 1992). Higher infestations of corn earworm in soybean, coupled with their ability to reduce yield both directly and indirectly have forced producers to look for a solution. Soybeans have more options for corn earworm control than most crops including cotton (Smith 2022). However, due to resistance issues, many insecticides have proven ineffective in corn earworm control. This pest has been documented to be resistant to organophosphates, carbamates, and cyclodienes (Plapp 1971, Sparks 1981). Until recently, pyrethroid insecticides provided good control of corn earworm for Mississippi producers, however many populations have become resistant to pyrethroids as well (Musser et al. 2010). As a result, fewer insecticide classes provide control, and the effectiveness of those products is declining.

Soybean looper is a pest that migrates into the U.S. from Central and South America generally arriving in the midsouth around August and September (Crow et. al 2023). Soybean loopers have become a costly pest to control due to increased resistance (Mascarenhas and Boethel 1997). Insecticide failures, and the soybean loopers' sheer ability to feed and defoliate in mass quantities has increased concerns for producers (Mascarenhas and Boethel 1997). Soybean loopers can consume large areas of leaves, leaving behind only the larger leaf veins giving the leaves a lace-like appearance (Herzog 1980, Huff 2020). Soybean looper sweep net threshold is lower than some of the other defoliation caterpillars because soybean loopers tend to feed in the lower part of the canopy, making it harder to scout with a sweep net (Owen 2012). Soybean looper, like many other defoliating caterpillars, has 90% of its lifetime foliage consumption occurring during the last three days of the last instar (Catchot et al. 2015).

Soybean loopers have become increasingly resistant to multiple classes of insecticides. For example, during a ten-year span from the 1960s to 1970s soybean looper developed resistance to all classes of available insecticides (Rice 2022). Soybean looper is currently resistant to carbamates, cyclodienes, organophosphates, and pyrethroids (Mascarenhas and Boethel 1997). In the mid-1980s, reports of properly applied but failed applications with pyrethroids started to appear (Felland et al. 1990). It has been documented on numerous occasions that increased resistance to pyrethroids by soybean loopers appears in areas where soybeans and cotton are grown closely together (Felland et al. 1990, Leonard et al. 1990, Mink and Boethel 1992, and Owen 2012).

Insect growth regulators (IGRs) have largely replaced the use of organophosphates, carbamates, and pyrethroids (Rice 2022). Another commonly used insecticide class to control soybean looper and corn earworm is diamides. Today, most soybean looper infestations are treated with chlorantraniliprole, methoxyfenozide, spinetoram, and various combinations of these products mixed with other insecticide classes (Crow et al. 2023). The mixing of different classes of insecticides for a single product has been increasingly popular, because it slows the rate of resistance and provides different modes of action to kill the target pest (US EPA 2023). IGRs have become a common insecticide class when co-applying with a fungicide. During the R3/R4 growth stage many producers in Mississippi have benefitted from making automatic fungicide applications in soybean for over a decade (Allen and Irby 2018). With this automatic fungicide application, many producers have started adding an insecticide to the tank to target late season pests to reduce cost by decreasing the number of trips made across the field. In the late 1990's, some state extension agencies like the University of Georgia were recommending preventative applications of insecticides at R3 (Hudson 1998). IGRs have become routinely applied insecticides for this management strategy, due to their relatively low cost and previous effectiveness as preventative insecticides. Studies conducted in the early 2000's in Louisiana demonstrated diflubenzuron and methoxyfenozide as being effective in preventative management for lepidopteran pests of soybean during the late season (Willrich 2001). Making an automatic application can be controversial, however when pests are present, and the correct product is used , it can be extremely effective (Catchot et al. 2018). In some cases, this automatic application made when pests are present carry a producer to harvest. Although previously, IGR's have demonstrated control of late season lepidopteran pests of soybean, with changing production practices, this management strategy should be reevaluated. Therefore, the objective of this study was to evaluate the use of insect growth regulators compared to an industry standard tank mixed with a fungicide at the R3-R4 growth stage to determine the impact on late-season insect management.

### 3.3 Materials and Methods

During 2022 and 2023, small plot replicated trials were conducted in Stoneville, MS (five sites) and Sidon (one site), MS. A randomized complete block design with four replications and a factorial arrangement of treatments was implemented. Plots were four rows wide on 101cm row spacing and 12.19m long. During 2022, AG47XF0 (Asgrow Seed Co LLC, Creve Coeur, MO) was planted on 21 June for one trial and AG46XF2 (Asgrow Seed Co LLC, Creve Coeur, MO) was planted on 7 July for another trial both at 296,520 seeds per hectare at 3cm depth. During 2023, four trials were planted all at 296,520 seeds per hectare at 3cm depth. AG46XF3 (Asgrow Seed Co LLC, Creve Coeur, MO) was planted in four different locations on 5 June, 20 June, 21 June, and 13 July.

At the R3 growth stage, applications were made using the following treatments: chlorantraniliprole (Prevathon®; FMC Corporation, Philadelphia, PA) at 52 g ai $ha^{-1}$ , methoxyfenozide (Intrepid 2F®; Corteva Agriscience, Indianapolis, IN) at 105 g ai $ha^{-1}$ , novaluron (Diamond®; ADAMA, Raleigh, NC) at a rate of 44 g ai $ha^{-1}$, diflubenzuron (Dimilin® 2L; Chemtura Agrosolutions, Middlebury, CT) at 70 g ai $ha^{-1}$, and lambda-cyhalothrin (Warrior II, Syngenta Crop Protection US, Greensboro, NC) at 35 g ai $ha^{-1}$ with and without pydiflumetofen and difenoconazole (Miravis Top, Syngenta Crop Protection US, Greensboro, NC) fungicide at a rate of 200 g ai $ha^{-1}$. Each of the treatments were compared to an untreated control. All plots were sprayed with a Mudmaster (Bowman Manufacturing©, Newport, AR) using TeeJet® (TeeJet® Technologies, Glendale Heights, IL) hollow cone TX-6 nozzles with a pressure of 413 kPa and at 93.5 L $ha^{-1}$. Trials were managed according to Mississippi State University Extension recommendations. Plots were sampled at 7, 14, 21, and 28 days after treatment (DAT) by taking 25 sweeps from the center two rows using a 38cm diameter sweep net. The total number of soybean loopers and corn earworms were recorded for each plot. Once plots had matured, the center two rows from every plot were harvested for comparison using a two row combine. Moisture corrected to 13%, and weight were all measured and used to determine kilograms per hectare for each plot.

Another study was conducted on various producer's farms throughout the Mississippi Delta (Table 3.1). Plots were planted at the recommended planting rate of Mississippi soybean between the end of April and June. Studies were conducted as a randomized complete block with three replications, plots that were 16 rows wide on 101cm row spacing running the entire length of the field, with the minimum plot size of 0.40 ha. Treatments were also applied at the R3 growth stage as described above. Insecticide treatments included methoxyfenozide (Intrepid 2F®; Corteva Agriscience, Indianapolis, IN) at 105 g ai $ha^{-1}$, novaluron (Diamond®; ADAMA, Raleigh, NC) at 44 g ai $ha^{-1}$, and diflubenzuron (Dimilin® 2L; Chemtura Agrosolutions, Middlebury, CT) at 70 g ai $ha^{-1}$. All insecticide were compared to an untreated control. On farm trials were sampled as described above.

Table 3.1 Locations and application dates for on farm trials in the Mississippi Delta during 2022 and 2023.

| Year | Location | Coordinates | Application Date |
|---|---|---|---|
| 2022 | Hollandale 2022 | 33.1138, -90.5146 | 29 Jun |
| 2022 | Leland 2022 | 33.2729, -90.5150 | 29 Jun |
| 2022 | Leland 2022 | 33.2708, -90.5138 | 29 Jun |
| 2022 | Drew 2022 | 33.5002, -90.2922 | 29 Jul |
| 2022 | Stoneville 2022 | 33.2458, -90.5443 | 3 Aug |
| 2023 | Leland 2023 | 33.2729, -90.5150 | 22 Jun |
| 2023 | Leland 2023 | 33.2708, -90.5138 | 22 Jun |
| 2023 | Choctaw 2023 | 33.3338, -90.4540 | 18 Jul |
| 2023 | Stoneville 2023 | 33.2458, -90.5443 | 15 Aug |
| 2023 | Arcola 2023 | 33.1637, -90.5343 | 15 Aug |

## 3.4 Data Analysis

Corn earworm infestations were low during both years of the study; therefore, the data were combined across both years for small plot studies. However, soybean looper infestations were drastically different in the small plot studies from one year to the next and therefore were analyzed separately. Soybean looper densities were similar across years in the on-farm trials, therefore data was analyzed across years. All trials were analyzed with a general linearized mixed model analysis of variance (PROC GLIMMIX, SAS 9.4, SAS Institute Inc). PROC MEANS was used to calculate means and standard errors, and Kenward-Roger was used to determine the degrees of freedom. All means were separated using Fisher's Protected LSD $\alpha=0.05$. The fixed effect for the small plot trials was treatment while the random effects were year, trial, replication, and year by trial. However, the yield from the small plot trials was analyzed by using treatment for the fixed effect and trial, replication, and trial nested within replication for the random effects. For on farm trials, treatment was set as a fixed effect; location, replication, and year by location were set as random effects. Soybean looper density data was analyzed by sample date however, corn earworm densities were extremely low and could not be analyzed.

## 3.5 Results

## 3.6 Corn Earworm Small Plot Trials

No interaction between insecticide, fungicide, and days after treatment was observed for corn earworm densities ($F$=0.80; df=15, 720.8; $P$=0.68). Also, no interaction between insecticide treatment and fungicide treatment ($F$=0.47; df=5, 720; $P$=0.80), insecticide treatment and days after treatment ($F$=0.47; df=15, 720; $P$=0.33), or fungicide and days after treatment ($F$=0.95; df=3,1; $P$=0.62) were observed. No effect of insecticide ($F$=0.98; df=5, 720; $P$=0.43), fungicide ($F$=0.02; df=1, 720; $P$=0.88), or days after treatment ($F$=2.67; df=3,1; $P$=0.42) was observed either (Figure 3.1).

## 3.7 Soybean Looper Small Plot Trial 2022

No interaction between insecticide, fungicide, and days after treatment was observed for soybean looper densities ($F$=0.18; df=15, 205.3; $P$=0.9997). Also, no interaction between insecticide treatment and fungicide treatment ($F$=0.17; df=5, 184; $P$=0.9739), insecticide treatment and days after treatment ($F$=0.22; df=15, 205.3; $P$=0.9991), or fungicide and days after treatment ($F$=0.53; df=3,142.8; $P$=0.6607) were observed. No effect of insecticide ($F$=1.01; df=5, 184; $P$=0.4132) or fungicide ($F$=0.01; df=1, 184; $P$=0.9042) was observed. Days after treatment had a significant effect on soybean looper densities ($F$=39.22; df=3,142.8; $P$=<0.0001) (Figure 3.2). Densities were highest at 14 DAT, however it did not separate from 7 DAT. Soybean looper densities did not differ between 7 DAT and 21 DAT, while densities at 28 DAT was significantly lower than that observed the other rating dates, with less than ten soybean loopers per plot (Figure 3.2).

## 3.8 Soybean Looper Small Plot Trial 2023

An interaction between days after treatment and insecticide was observed ($F$=1.84; df=17, 720; $P$=0.0262). Overall, soybean looper densities were low (<10 larvae / 25 sweeps). The highest densities were observed at 7 DAT, with densities declining at subsequent sample dates. Novaluron resulted in similar densities of loopers at all sample dates. Soybean looper densities were lower at 28 DAT in plots treated with diflubenzuron compared to the same plots at 7 DAT. Methoxyfenozide resulted in similar densities of soybean looper across sample dates. Chlorantraniliprole also resulted in similar densities of soybean looper across sample dates. Lambda-cyhalothrin treated plots had greater looper densities at 7, 14, and 21 DAT compared to 28 DAT. Differences in soybean looper densities between insecticide treated plots and the untreated control were only observed at 7 and 14 DAT (Figure 3.3).

### 3.9 Small Plot Yields

During 2022, no interaction between insecticide and fungicide was observed for yield (*F*=0.91; df=5,77; *P*=0.4782) However, an effect of insecticide (*F*=6.02; df=5,77; *P*=<.0001) and fungicide (*F*=10.67; df=1,77; *P*=0.0016) was observed. Only chlorantraniliprole and methoxyfenozide resulted in greater yields than that observed in the untreated control (Figure 3.4). Also, the application of fungicide resulted in higher yields. (Figure 3.5). During 2023, no interaction between insecticide and fungicide was observed (*F*=0.98; df=5,121; *P*=0.4299). Also, no effect of insecticide (*F*=1.00; df=5,121; *P*=0.4180) or fungicide (*F*=3.44; df=1,121; *P*=0.0660) was observed for yield (Figure 3.4 and 3.5).

### 3.10 On Farm Trials

At 7 DAT, no differences among treatments were observed for soybean looper (*F*=2.35; df=3,75.04; *P*=0.0795) (Figure 3.6). At 14 DAT, novaluron and methoxyfenozide resulted in fewer soybean looper larvae compared to the untreated control (*F*=6.51; df=3,74.96; *P*=0.0006) (Figure 3.6). At 21 DAT, no difference between treatments were observed for densities of soybean loopers (*F*=0.12; df=3,58.33; *P*=0.9488). At 28 DAT, plots treated with novaluron had higher soybean looper densities than those in the untreated plots (*F*=3.83; df=3,70.98; *P*=0.0134) (Figure 3.6). Corn earworm densities were extremely low and could not be analyzed.

### 3.11 Discussion

Soybean looper and corn earworm are economically important insect pests of soybean in Mississippi. However, the extent and severity of infestations can vary from year to year (Musser et al. 2022). Soybean looper densities tend to be higher during mid-August to September (Carner et al. 1974). With widespread adoption of the early soybean production system, only later planted soybeans are generally at an increased risk of damaging infestations of insect pests (Bateman 2017). In both the small plot and large plot on farm trials, corn earworm densities were below threshold. During 2022, infestations of soybean loopers did occur in the small plot trials, however there were no differences among treatments regardless of sample date. During 2023, soybean looper densities did not exceed threshold, while soybean looper densities in the on-farm trials were below threshold also. These results demonstrate that insect infestations, particularly soybean looper and corn earworm are unpredictable. Also, none of the insecticides evaluated resulted in adequate mortality of soybean looper beyond 1 DAT in bioassays described in chapter two. During 2022, yield improvements were observed in the small plot trials compared to the untreated control. However, it is unknown, but suspected that greater benefit may have occurred if applications had been made based on scouting. The average cost of an insecticide application for soybean looper and corn earworm being $40.77 and $49.42 per hectare, respectively (Musser et al. 2022). This would be a substantial loss should infestations not occur. Some of the IGR insecticides may be less costly. However, diflubenzuron, novaluron, and methoxyfenozide, did not provide acceptable control. There are a few instances where pest infestation is predictable. Making efficacious or cost-effective insecticide applications based on growth stage and/or date is generally not feasible. In most of the soybean production areas of Mississippi, insect infestation can vary greatly during the season and across years. Due to this and the cost of insecticide applications, it is more economical to base insecticide applications on scouting and established thresholds.

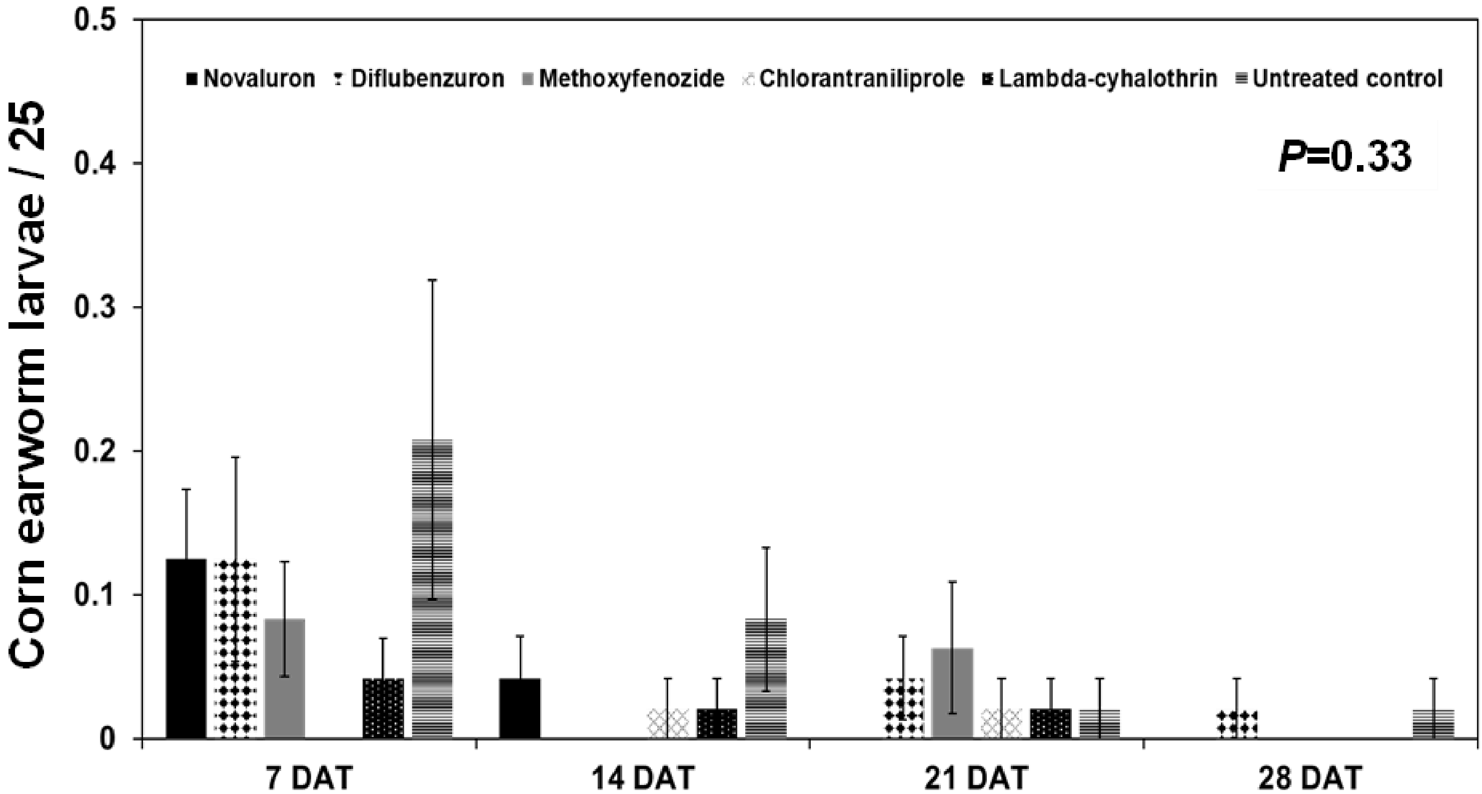


Figure 3.1 Influence of insecticide treatment applied at the R3 growth stage and days after treatment ($F$=1.13; df=15, 720; $P$=0.33) on corn earworm densities in soybean small plot trials during 2022-2023. Bars with a common letter are not significantly different (FPLSD, $P>F$ = 0.05).

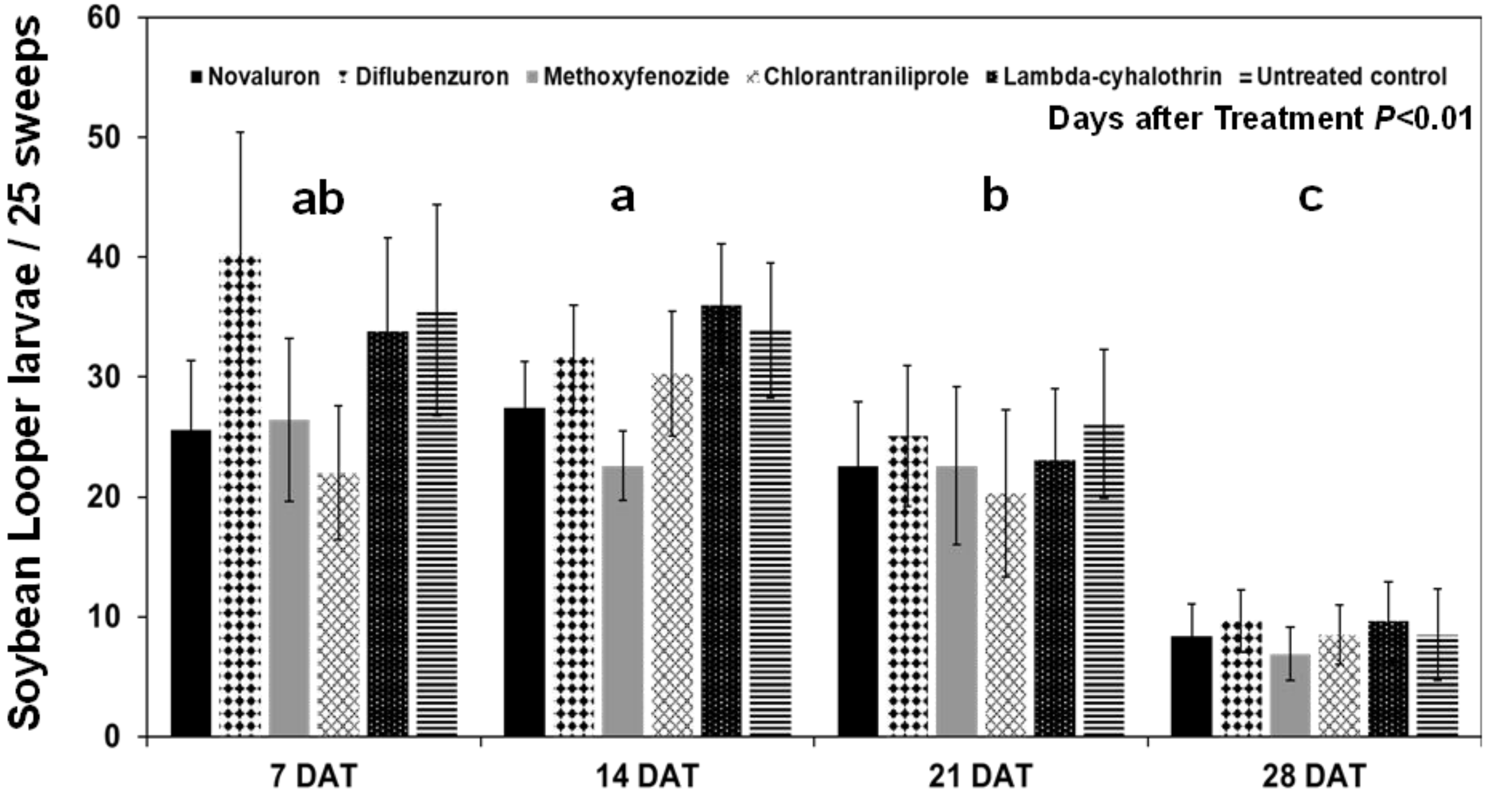


Figure 3.2 Influence of days after treatment ($F$=39.22; df=3, 142.8; $P$<0.01) of insecticides applied at the R3 growth stage on soybean looper densities in soybean small plot trials during 2022. Bars (DAT) with a common letter are not significantly different (FPLSD, $P>F$ = 0.05).

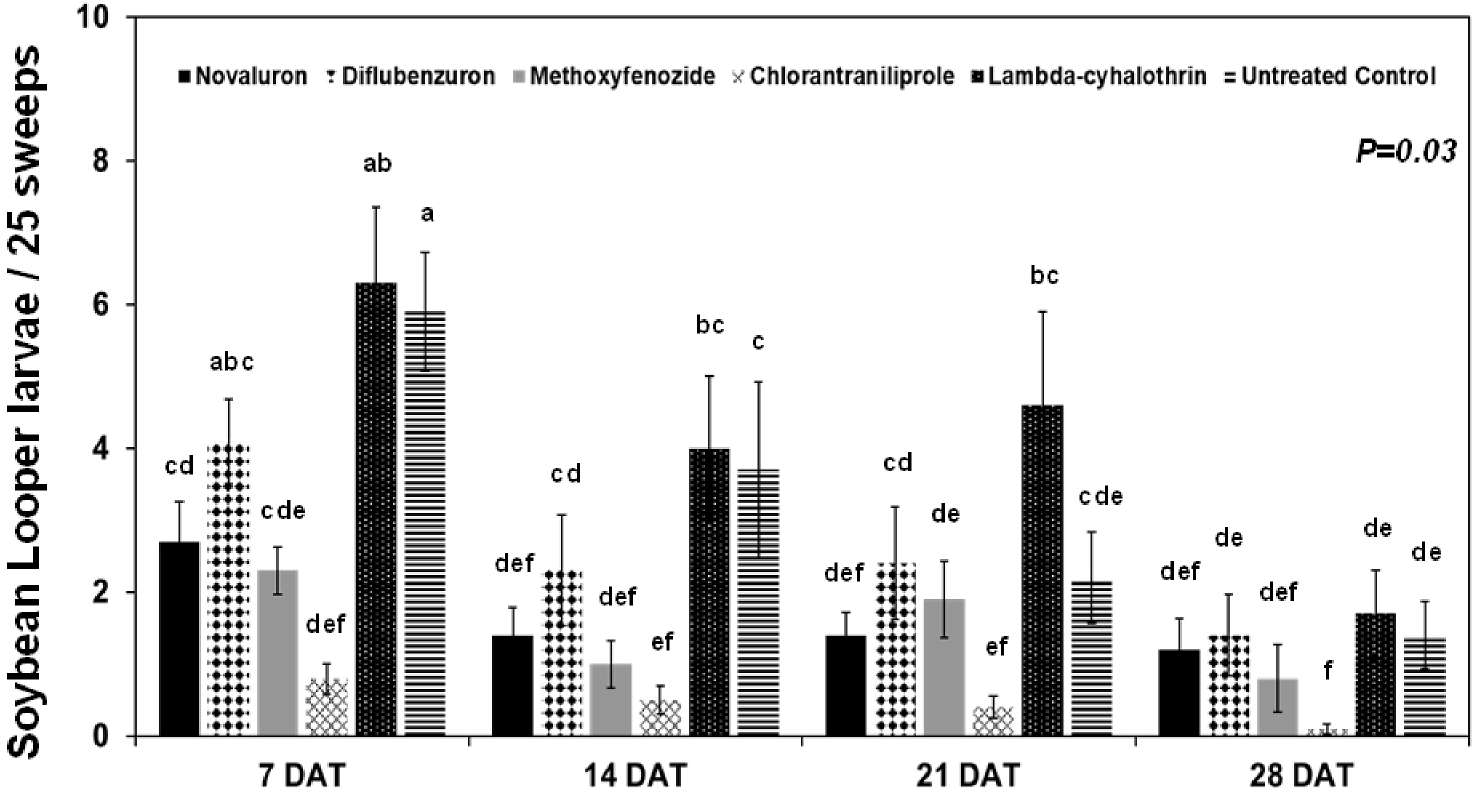


Figure 3.3 Influence of insecticide treatment applied at the R3 growth stage and days after treatment (*F*=1.84; df=15, 720; *P*=0.03) on soybean looper densities in soybean small plot trials during 2023. Bars with a common letter are not significantly different (FPLSD, *P*>*F* = 0.05).

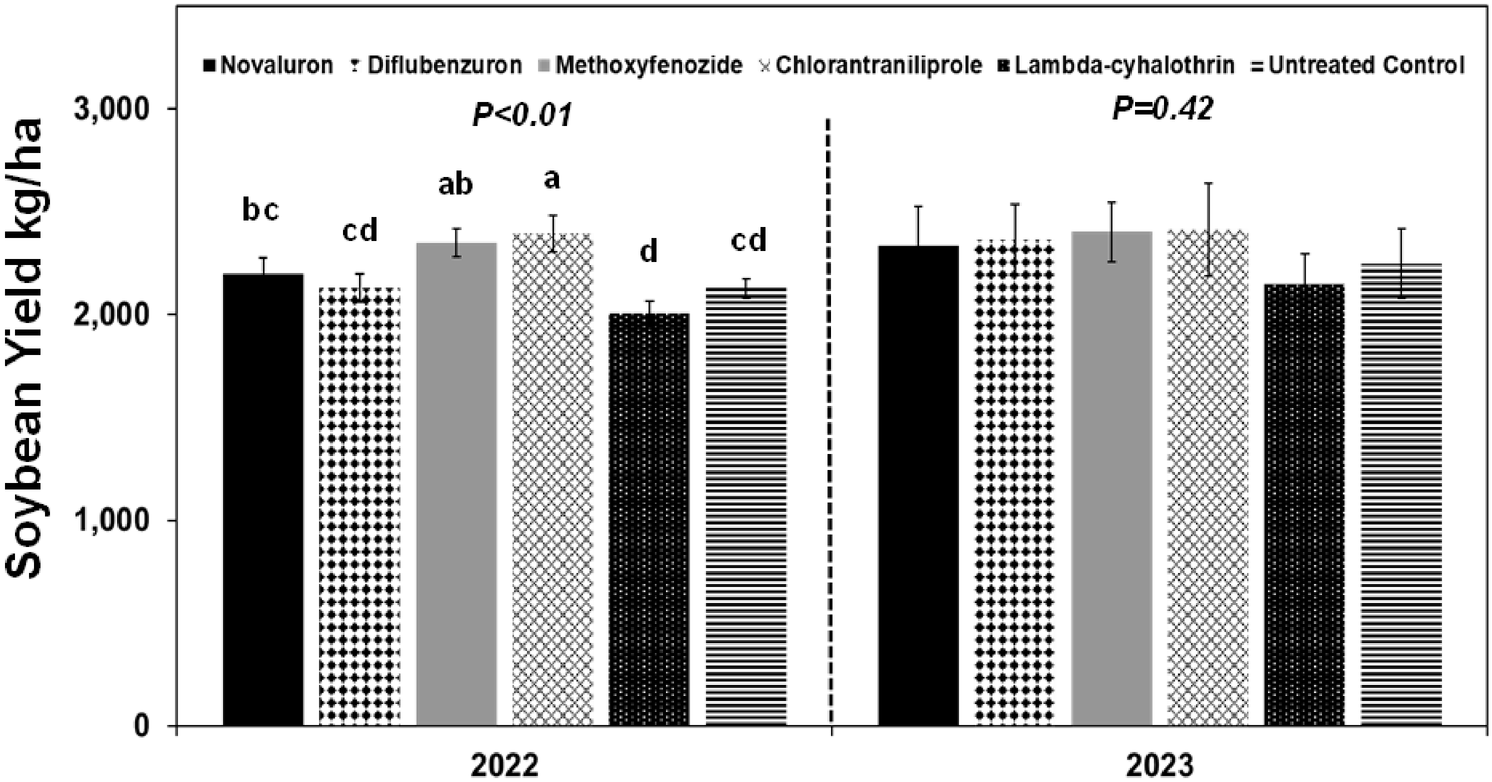


Figure 3.4 Influence of insecticides applied at the R3 growth stage on soybean yield in small plot trials during 2022 ($F$=6.02; df=5, 77; $P$<0.01) and 2023 ($F$=1.0; df=5, 121; $P$=0.42). Bars within a year with a common letter are not significantly different (FPLSD, $P>F$ = 0.05).

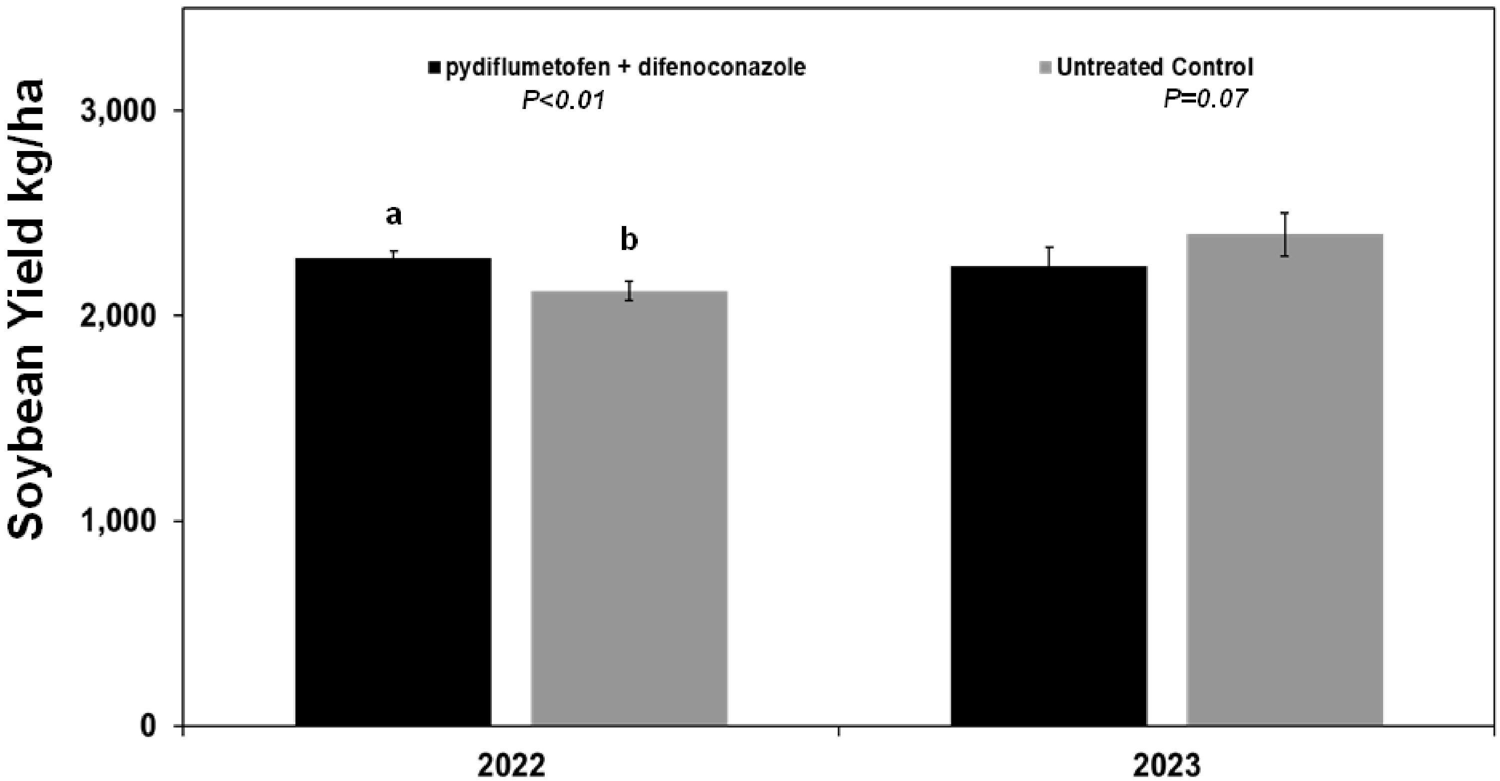


Figure 3.5 Influence of fungicide treatment applied at the R3 growth stage on soybean yield in small plot trials during 2022 ($F$=10.67; df=1, 77; $P$<0.01) and 2023 ($F$=3.44; df=1, 121; $P$=0.07). Bars within a year with a common letter are not significantly different (FPLSD, $P$>$F$ = 0.05).

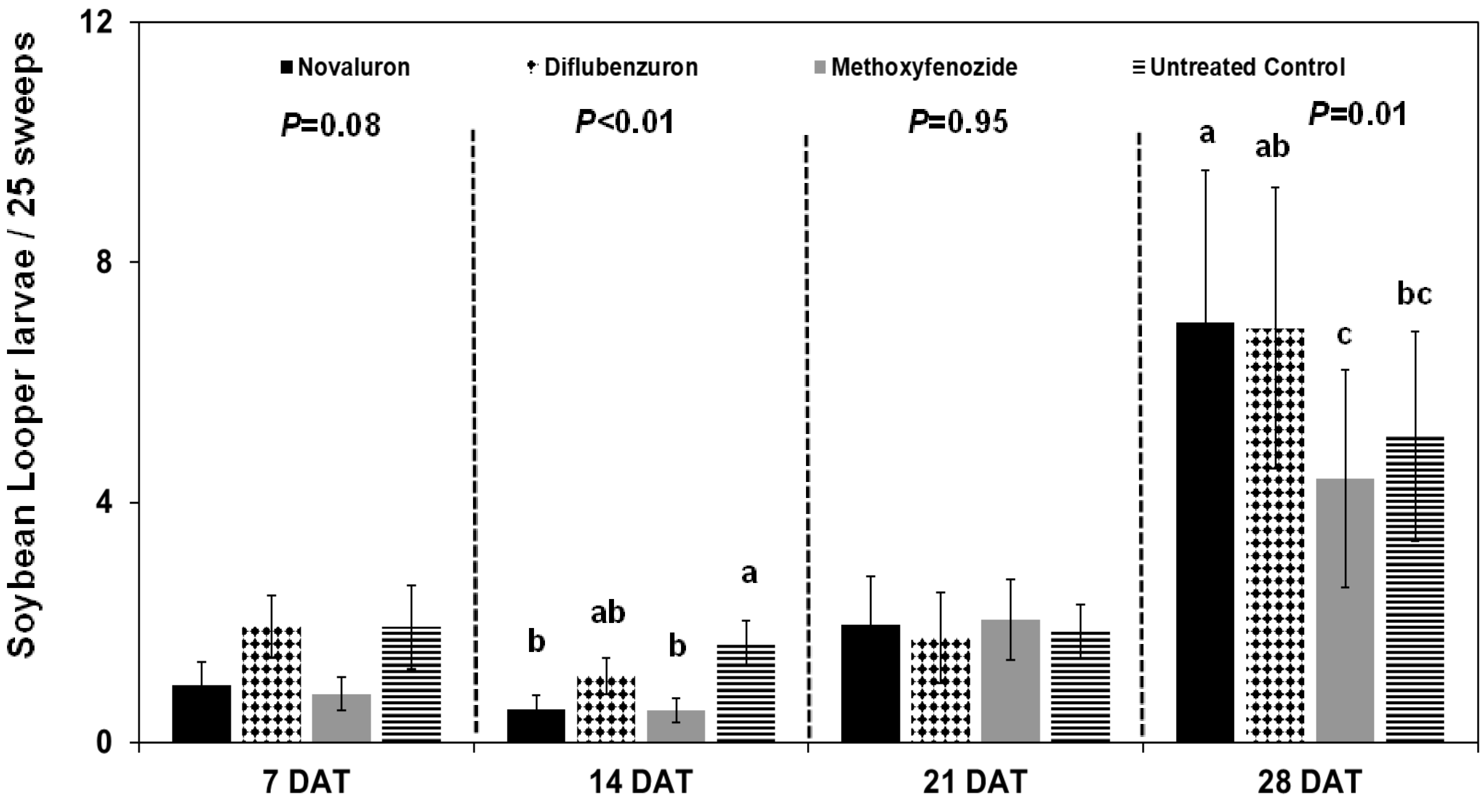


Figure 3.6 Performance of selected insecticides applied at the R3 growth stage of soybeans against soybean looper in large plot on farm trials during 2022 and 2023 at 7 DAT ($F$=2.35; df=3, 75.04; $P$=0.08), 14 DAT ($F$=6.51; df=3, 74.96; $P$<0.01), 21 DAT ($F$=0.12; df=3, 58; $P$=0.95), and 28 DAT ($F$=3.83; df=3, 70.98; $P$=0.01). Bars within a sample date with a common letter are not significantly different (FPLSD, $P>F$ = 0.05)

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