

ARTHROPOD MANAGEMENT & APPLIED ECOLOGY

Incorporating Honey Bee Toxicity into Foliar Insecticide Selection for Insect Pest Management in Cotton

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ABSTRACT

Cotton, *Gossypium hirsutum* (L.), is a vital crop across the southern U.S. Numerous insect species are yield-limiting pests throughout the cotton growing regions of the U.S., often requiring multiple foliar insecticide applications annually. Those insecticides pose an indirect risk to honey bees, *Apis mellifera* (L.), and other pollinators through contaminated nectar, pollen, or other routes during cotton bloom. Currently, pest managers only consider efficacy against the target pest when selecting insecticides and give little consideration to honey bee toxicity. The objective of this study was to incorporate honey bee acute toxicity data as a non-target insect pollinator and insecticide efficacy data against target pests into insecticide selection. Efficacy trials were conducted in mid-southern U.S. to determine the efficacy of eight and five currently recommended insecticides against tarnished plant bug (*Lygus lineolaris* [Palisot de Beauvois]) and bollworm (*Helicoverpa zea* [Boddie]), respectively. Insecticides were ranked based on historical published data for their toxicity to honey bees and efficacy against the targeted pest based on standardized trials across multiple states. The rankings were

multiplied to give equal weight to honey bee toxicity and pest efficacy. Novaluron, sulfoxafflor, and flonicamid provided the best balance between efficacy against tarnished plant bug and acute toxicity to honey bees. Chlorantraniliprole provided the best balance between honey bee toxicity and bollworm efficacy. These findings can be used to improve integrated pest management strategies by maximizing control of pests while considering honey bee toxicity.

Cotton, *Gossypium hirsutum* (L.), is an important crop across the southern U.S. with 4.5 million hectares planted in the 2023 growing season (USDA NASS, 2024). Cotton has a wide range of uses including the manufacturing of clothing, textiles, oils, livestock feed, and medicinal products (Egbuta et al., 2017). In the U.S. alone, cotton production and use generate business revenues of \$120 billion annually (National Cotton Council, 2019). Major pests of cotton include tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); cotton aphid, *Aphis gossypii* (Glover); bollworm, *Helicoverpa zea* (Boddie); tobacco thrips, *Frankliniella fusca* (Hinds); and numerous other secondary pests. The production of cotton relies on integrated pest management (IPM) strategies that incorporate crop management practices such as planting date and variety selection (Adams et al., 2013), planting arrangement (Gore et al., 2010), transgenic technologies (Calvin et al., 2021), use of at-planting insecticides (Cook et al., 2011), fertilizer management (Samples et al., 2019), and irrigation scheduling (Bottrell and Adkisson, 1977; Wood et al., 2019). Scouting and intervention with foliar insecticides remain important components of IPM in cotton, especially in the mid-southern region that includes Arkansas, Mississippi, Louisiana, Tennessee, and Missouri (Crow et al., 2020; George et al., 2021).

In the mid-southern region of the U.S., multiple insecticide applications are generally required each

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year to prevent severe economic losses from insect pests in cotton (Cook and Threet, 2021). Foliar applications consist of spraying directly on the leaves of plants to allow greater contact or effective absorption throughout the plant (Wakeford, 2024). In addition to crop management practices, monitoring pest populations in the field and spraying insecticides based on established economic thresholds are critical components of IPM. The economic threshold is the level of pest population or injury when a spray application should be made to prevent the pest from reaching the economic injury level, the level where cost of control equals the cost of loss (Pedigo et al., 1986). Some states have established economic thresholds that incorporate levels of beneficial insects (predators and parasitoids) in addition to pest populations (Zhang and Swinton, 2009), but few studies have attempted to quantitatively incorporate pollinator toxicity into insecticide selection.

Pollinators contribute nearly \$18 billion to the U.S. economy annually from an estimated 2.8 million colonies (Nowierski, 2020). There has been a decline in pollinators and pollinator diversity in recent years (Potts et al., 2010). Agricultural intensification along with various environmental stressors played a key role in the loss of pollinators and biodiversity (Stuligross and Williams, 2020). A recent review (Chakrabarti, 2019) highlighted that honey bee, *Apis mellifera* (L.), loss can be attributed to stressors such as pests, parasites, pathogens, lack of genetic diversity, poor nutrition, transportation, environmental factors, and pesticide use. Insecticide applications for target pests are crucial in row crops but impose threats to beneficial insects in the landscape (Desneux et al., 2007). Pollinators, such as honey bees, encounter pesticides in the landscape mainly while foraging and collecting contaminated nectar and pollen from plants that have been sprayed and bringing those resources back to the colony or nests (Chakrabarti, 2019). Honey bees employed for crop pollination and/or honey production often face an increased risk to pesticide exposures due to their placement in agricultural landscapes. Cotton is a major crop for honey production, especially in the southeastern U.S. (Harris, 2023). There has been little work conducted on pollinator safety when making insecticide applications for pest management in row crops such as cotton. Although foliar insecticides are important for crop protection, they have been associated with honey bee decline in many parts of the world (Krupke et al., 2012; Lawrence

et al., 2016). The toxicity to honey bees (Zhu et al., 2015) and level of control of pests in cotton differs for multiple insecticides. Therefore, it is important to consider both efficacy against the target pest and toxicity to honey bees when choosing insecticides for crop protection when honey bees are present. Currently, pest managers consider efficacy against the target pest and cost when selecting a specific insecticide with little to no consideration for honey bee safety. The objective of the current study was to develop an insecticide selection method for agricultural pest managers to use in IPM systems using two key pests of flowering cotton, tarnished plant bug, and bollworm, as models.

MATERIALS AND METHODS

Honey Bee Toxicity Rankings. This study incorporates honey bee safety into insecticide selection for IPM in cotton as a proof of concept using only acute toxicity and does not consider various chronic effects of the insecticides on colony health. Honey bee acute toxicity rankings were based on research by Zhu et al. (2015) in which the authors related laboratory toxicity data to typical field use concentrations. In that study, they conducted concentration-mortality bioassays with formulated insecticides using a Potter-Precision Laboratory Spray Tower to determine the lethal concentration (LC) 1 and LC₉₉ values. Additionally, the authors calculated a field use concentration (FUC) by dividing the typical average use rate for each insecticide (based on local extension service recommendations) by the typical average use volume (93.5 L Ha⁻¹ or 10 GPA). From those values, the authors calculated ratios of FUC to LC₁ and LC₉₉ values for each insecticide to determine potential honey bee toxicity from field use in pest management. To determine honey bee toxicity rankings in our study, we took the average of the FUC:LC₁ and FUC:LC₉₉ ratios as reported by Zhu et al. (2015) for the insecticides evaluated for target pest control.

A total of 12 standardized insecticide efficacy trials were conducted in cotton from 2020 to 2021 in the Mid-South states of Arkansas, Mississippi, Louisiana, Tennessee, and Texas. These studies targeted tarnished plant bug and bollworm, the two most important insect pests of flowering cotton in this region. Cotton varieties planted and plot dimensions for these experiments varied across locations, but plots were generally 3.86 or 4.06 m wide (4 rows on

0.97- or 1.02-m centers) by 9.1 to 15.2 m in length depending on location and year. Cotton was planted, cultivated, and managed according to local extension service recommendations in each state. Planting dates varied from 24 April to 30 May depending on location and year. Experiments were conducted as a randomized complete block design with four replications. Each insecticide was randomly applied to an individual plot in each block based on randomization maps generated from Agricultural Research Manager (GDM Solutions, Brookings, SD) and each individual trial had a unique randomization. Insecticides were applied at the locally recommended rates using a high-clearance sprayer. The sprayers were calibrated to deliver a carrier volume of 93.5 to 140.0 L ha⁻¹ depending on location. A total of eight insecticides were evaluated against tarnished plant bug and five for bollworm.

Tarnished Plant Bug. Data used for tarnished plant bug efficacy were published by Smith et al. (2023). Detailed methods for tarnished plant bug trials are described in Smith et al. (2023). Applications were made in flowering cotton when tarnished plant bug populations were at or above the current economic threshold of three tarnished plant bugs per 1.52 row m (Crow et al., 2025) using a black drop cloth. The insecticide treatments evaluated (rate in kg ai ha⁻¹) were imidacloprid (0.06), flonicamid (0.01), thiamethoxam (0.056), oxamyl (0.40), dicotophos (0.56), acephate (0.84), novaluron (0.065), and sulfoxaflor (0.053). Tarnished plant bug densities were determined at 2 to 4, 5 to 8, and 9 to 14 d after treatment by taking two drop cloth samples in each plot. A black 0.76-m long drop cloth was placed on the ground between the two center rows of each plot and all plants the length of the drop cloth were vigorously shaken over the cloth to dislodge tarnished plant bugs. For each insecticide, percentage control was calculated across all ranking timings and locations by dividing the number of tarnished plant bugs in each treatment within a replication by the number of tarnished plant bugs in the untreated control group within the same replicate and subtracting that number from 100.

Bollworm. Data used for bollworm efficacy were not previously published. A total of five studies were conducted in Arkansas, Mississippi, Tennessee, Texas, and Louisiana during 2022 and 2023. All bollworm studies were conducted with a cotton variety that did not contain lepidopteran-active Bt proteins (Deltapine 1822 XF, Bayer CropScience, Raleigh,

NC) to ensure traditional pesticide use patterns. Applications were made in flowering cotton fields when bollworm populations were at or above the current economic threshold (4 larvae per 100 plants; Crow et al., 2025). The insecticide treatments (rate in kg ai ha⁻¹) were chlorantraniliprole (0.075), a premix of chlorantraniliprole and lambda cyhalothrin (0.11, Besiege, Syngenta Crop Protection, Greensboro, NC), a premix of chlorantraniliprole and bifenthrin (0.19, Elevest, FMC Corporation, Philadelphia, PA), a premix of spinetoram and methoxyfenozide (0.21, Intrepid Edge, Corteva AgriSciences, Indianapolis, IN), acephate (0.84) tank mixed with bifenthrin (0.11), and an untreated control. Bollworm densities were determined 7 and 13 d after treatment by making visual inspections in each plot. Visual inspections for bollworms consisted of randomly observing 25 terminals, 25 flowers, 25 squares, and 25 bolls of cotton plants from each plot for the presence of bollworm larvae. For each insecticide, percentage control was calculated by dividing the number of bollworm larvae (all instars) from all structures in each treatment within a replication by the number of bollworm larvae in the untreated control within the same replicate and subtracting that number from 100.

Data Analyses. Insecticides were ranked based on their toxicity to honey bees (1 to 8 for tarnished plant bug insecticides and 1 to 5 for bollworm insecticides) and efficacy against the targeted pest averaged across all years, locations, and sample dates weighted equally. The least acutely toxic insecticide for honey bees was given the lowest honey bee rank and the most acutely toxic insecticide for honey bees was given the highest honey bee rank. Conversely, the insecticide with the most efficacy against the target pest was given the lowest rank and the insecticide with the lowest efficacy against the target pest was given the highest rank. The rankings for insecticide efficacy were determined independently for each test within a year and location. To determine the insecticide that provided the greatest level of control while considering honey bee toxicity, the insecticide efficacy rank was multiplied by the honey bee toxicity rank. This ranking method gives equal weight to both honey bee toxicity and insecticide efficacy so that the final score provides an equal compromise between honey bee acute toxicity and pest control. We multiplied ranks to give different weights to pest efficacy and honey bee toxicity (i.e., weight pest efficacy by 75% and weight honey bee toxicity by 25% or vice versa); this did not change overall

rankings with these insecticides and pests. Based on this method, the insecticide with the lowest ranking would indicate the best choice for balancing pest efficacy and honey bee toxicity.

Percentage pest control, insecticide rankings, and insecticide selection rank were analyzed with a generalized linear mixed model analysis of variance (PROC GLIMMIX, SAS 9.4, SAS Institute, Cary, NC). Insecticide treatment was considered a categorical fixed effect in each model. For percentage pest control and pest control rank, replication nested in year by location was considered the random effect in each model. For insecticide selection rank, location nested in year was considered the random effect. Means were calculated with LSMEANS and separated based on Tukey's HSD test (Tukey, 1953).

RESULTS AND DISCUSSION

Tarnished Plant Bug. Foliar insecticides remain an important component of tarnished plant bug and bollworm management in cotton in the southern U.S. (Smith et al., 2023). Insecticide applications have increased over the years for tarnished plant bug control from 2.44 applications required in 2004 to 5.08 required applications in 2014 (Cook and Threet, 2021; Gore et al., 2014; Smith et al., 2023). The recent implementation of cultural practices

into IPM strategies has helped reduce the number of spray applications needed for insect control (Crow et al., 2021). In areas heavily infested by tarnished plant bug, follow up applications can be needed for adequate control (Cook and Threet, 2021; Crow et al., 2021). Currently, recommended insecticides for these pests have differing levels of acute toxicity to worker honey bees when exposed (Basu and Chakrabarti, 2015). The average of the FUC:LC₁ and FUC:LC₉₉ ratios as reported by Zhu et al. (2015) ranged from 0.67 for novaluron to 524 for dicotophos, meaning that dicotophos provides a much greater risk to honey bees than novaluron (Table 1). Based on these ratios, insecticide toxicity rankings for honey bees from lowest to highest were novaluron, flonicamid, sulfoxaflor, imidacloprid, oxamyl, thiamethoxam, acephate, and dicotophos. Despite these rankings, several of these insecticides have been shown to cause greater levels of chronic toxicity or sublethal effects that were not considered in the current study. For instance, several studies showed that neonicotinoids, such as imidacloprid and thiamethoxam, can have lasting impacts on colony health (Dively et al., 2015). Although novaluron was the least acutely toxic insecticide to worker honey bees, other research has shown that this insecticide can negatively affect honey bee reproduction and development (Fine, 2020; Fine et al., 2017, 2023).

Table 1. Variables used to rank insecticide selection for tarnished plant bug management in cotton that accounts for honey bee acute toxicity and efficacy against tarnished plant bug (TPB)

Insecticide	Application rate ^z (kg a.i. ha ⁻¹)	Avg. FUC:LC Ratio ^y	Honey bee Rank ^x	TPB Control % (SEM) ^w	Mean TPB Rank ^x (SEM)
Dicotophos	0.455	524	8	51.0 (2.7)b	4.36 (0.49)
Thiamethoxam	0.092	78.2	6	45.8 (2.8)bc	5.25 (0.48)
Imidacloprid	0.14	52.98	4	34.8 (2.6)d	6.67 (0.48)
Acephate	0.64	94.18	7	59.7 (2.8)a	3.58 (0.73)
Oxamyl	0.454	63.39	5	50.4 (2.7)b	4.67 (0.51)
Flonicamid	0.01	1.12	2	41.8 (2.8)c	5.64 (0.65)
Sulfoxaflor	0.033	9.13	3	65.5 (2.4)a	2.25 (0.63)
Novaluron	0.076	0.67	1	59.7 (2.4)a	3.17 (0.42)

^zInsecticide rate evaluated in field efficacy trials.

^yThe field use concentration to lethal concentration ratio (FUC:LC) is the average between the FUC:LC₁ and FUC:LC₉₉ ratios from Table 3 in Zhu et al. (2015).

^xInsecticide rankings for honey bee toxicity and tarnished plant bug efficacy range from 1 to 8 where 1 equals the least acutely toxic to honey bees and the most efficacious against tarnished plant bug, and 8 equals the most acutely toxic to honey bees and the least efficacious against tarnished plant bug. Honey bee toxicity rankings were determined based on the FUC:LC ratio. Tarnished plant efficacy rankings were based on percentage control.

^wMeans within a column sharing the same letter are not significantly different (Tukey's HSD; $p < 0.01$).

Although exposure to novaluron might not result in immediate mortality of individual bees, this decreased reproduction could lead to long-term colony declines. Similarly, sulfoxaflor has been classified as highly toxic by the Environmental Protection Agency (Corteva, 2022). Sulfoxaflor has been shown to have adverse lethal and sublethal effects, such as reduced survival, disrupted homing ability and increased oxidative stress and apoptosis, on honey bees and other bee species (Azpiazu et al., 2021). On the other hand, a recent study found no adverse impacts on honey bees when exposed to field-relevant concentrations of flonicamid at both field and laboratory settings (Meikle and Weiss, 2022).

Similar to variables observed with honey bee acute toxicity, the recommended insecticides provided varying levels of tarnished plant bug control ($F = 23.16$; $df = 7, 773$; $p < 0.01$). Sulfoxaflor, novaluron, and acephate resulted in greater control of tarnished plant bug than all other insecticides evaluated (Table 1). Dicrotophos resulted in greater control of tarnished plant bug than imidacloprid and flonicamid. These levels of control resulted in mean (SEM) tarnished plant bug efficacy rankings ranging from 2.25 (0.63) for sulfoxaflor to 6.67 (0.48) for imidacloprid (Table 1). Based on percentage control, insecticide efficacy rankings against tarnished plant bug from lowest (best control) to highest (least control) were sulfoxaflor, acephate, novaluron, dicrotophos, oxamyl, thiamethoxam, flonicamid, and

imidacloprid (Table 1).

When accounting for efficacy against tarnished plant bug and toxicity to honey bees, novaluron, sulfoxaflor, and flonicamid were determined to be the best choices to minimize honey bee acute toxicity and maximize control of tarnished plant bug (Fig. 1, $F = 16.79$; $df = 7, 79$; $p < 0.01$). Oxamyl and acephate were next, but special consideration should be given to these insecticides. Acephate was highly ranked for tarnished plant bug control but was one of the three most toxic insecticides to honey bees. Conversely, flonicamid was poorly ranked for tarnished plant bug control, but was one of the least acutely toxic insecticides for honey bees.

Bollworm. The average of the FUC:LC₁ and FUC:LC₉₉ ratios as reported by Zhu et al. (2015) ranged from 0.68 for chlorantraniliprole to 68.94 for acephate plus bifenthrin (Table 2). Based on these ratios, insecticide toxicity rankings for honey bees from the lowest to highest were chlorantraniliprole, chlorantraniliprole plus lambda-cyhalothrin, spinetoram plus methoxyfenozide, chlorantraniliprole plus bifenthrin, and acephate plus bifenthrin (Table 2).

Similar to variability observed with honey bee acute toxicity, the recommended insecticides provided varying levels of bollworm control ($F = 5.43$; $df = 4, 150$; $p < 0.01$). Chlorantraniliprole plus bifenthrin, chlorantraniliprole plus lambda-cyhalothrin, and chlorantraniliprole resulted in the best control

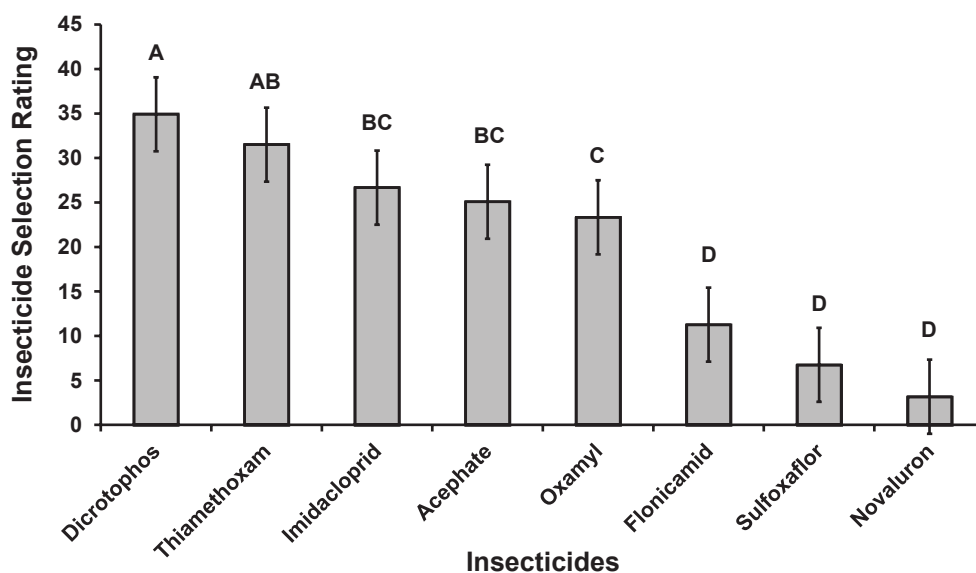


Figure 1. Insecticides recommended for tarnished plant bug control based on field efficacy and honey bee acute toxicity. Lower numbers equal greater tarnished plant bug control and lower honey bee toxicity. Higher numbers equal less tarnished plant bug control and greater honey bee toxicity. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

Table 2. Variables used to rank insecticide selection for bollworm management in cotton that accounts for honey bee acute toxicity and efficacy against cotton bollworm.

Insecticide	Application rate ^z (kg a.i. ha ⁻¹)	Avg. FUC:LC Ratio ^y	Honey bee Rank ^x	Bollworm Control % (SEM) ^w	Mean Bollworm Rank ^x (SEM)
Acephate + Bifenthrin	0.95	68.94	5	64.0 (6.1)b	5.00 (0.0)
Spinetoram + Methoxyfenozide	0.21	12.48	3	68.0 (6.2)b	3.25 (0.75)
Chlorantraniliprole	0.075	0.68	1	82.4 (2.6)a	2.00 (0.41)
Chlorantraniliprole + lambda-cyhalothrin	0.11	4.97	2	85.9 (2.6)a	2.50 (0.65)
Chlorantraniliprole + bifenthrin	0.19	22.19	4	86.2 (3.4)a	2.25 (0.48)

^zInsecticide rate evaluated in field efficacy trials.^yThe field use concentration by lethal concentration ratio (FUC:LC) is the average between the FUC:LC₁ and FUC:LC₉₉ ratios from Table 3 in Zhu et al. (2015).^xInsecticide rankings for honey bee toxicity and bollworm efficacy range from 1 to 5 where 1 equals the least acutely toxic to honey bees and the most efficacious against bollworm, and 5 equals the most acutely toxic to honey bees and the least efficacious against bollworm. Honey bee toxicity rankings were determined based on the FUC:LC ratio. Bollworm efficacy rankings were based on percentage control.^wMeans within a column sharing the same letter are not significantly different (Tukey's HSD; $p < 0.01$).

of bollworms of the insecticides tested (Table 2). No differences were observed between spinetoram plus methoxyfenozide and acephate plus bifenthrin. These levels of control resulted in mean (SEM) bollworm efficacy rankings ranging from 2.00 (0.41) for chlorantraniliprole to 5.00 (0.0) for acephate plus bifenthrin (Table 2). Acephate plus bifenthrin was ranked lowest in terms of bollworm efficacy and greatest in terms of honey bee acute toxicity in every test resulting in no standard error. Based on percentage control, insecticide efficacy rankings against bollworm from the lowest (best control) to the highest (least control) were chlorantraniliprole, chlorantraniliprole plus bifenthrin, chlorantraniliprole plus lambda-cyhalothrin, spinetoram plus methoxyfenozide, and acephate plus bifenthrin (Table 2). Although acephate plus bifenthrin provided the lowest level of bollworm control, this tank mix is often used when bollworm populations are low and other pests such as tarnished plant bug are present because it is a less expensive option compared to other insecticides labeled for bollworm.

When accounting for efficacy against bollworm and toxicity to honey bees, chlorantraniliprole was better than all other insecticides except chlorantraniliprole plus lambda-cyhalothrin (Fig. 2, $F = 19.74$; $df = 4, 10$; $p < 0.01$). Acephate plus bifenthrin was the least effective treatment based on pest efficacy and honey bee acute toxicity. No differences were observed between spinetoram plus methoxyfenozide, chlorantraniliprole plus bifenthrin, and chloran-

traniliprole plus lambda-cyhalothrin. Whereas spinetoram provides good bollworm control, methoxyfenozide provides little bollworm control (Lipsey et al., 2024).

IPM practices use biological, cultural, physical, and chemical control to manage insect pests in agronomic crops such as cotton (Lorenz et al., 2019). The foundation of IPM is built on the economic threshold and economic injury level concept (Lorenz et al., 2019). Getting an accurate estimate of the pest population is crucial when making decisions about using foliar insecticides in cotton. For tarnished plant bug, the development of populations resistant to multiple classes of insecticides (pyrethroids and organophosphates) has made insecticide selection more complicated for pest managers (Snodgrass, 1996; Snodgrass et al., 2008a, b, 2009). The introduction of Bt (*Bacillus thuringiensis* Berliner) cotton essentially eliminated tobacco budworm, *Chloridea virescens* (F.), as a pest but elevated the pest status of bollworm and changed the management considerations (Luttrell and Jackson, 2012).

Bollworm resistance to pyrethroids has been documented in the U.S. since the early 2000s (Hutchison et al., 2007) and has spread to most areas of the cotton belt making bollworm management in Bt cotton more difficult. Due to the widespread use of pyrethroids in multiple crops, these insecticides have become less effective in controlling target pests (Luttrell et al., 2015; Nadeem et al., 2022). Due to resistance to pyrethroids, they add little

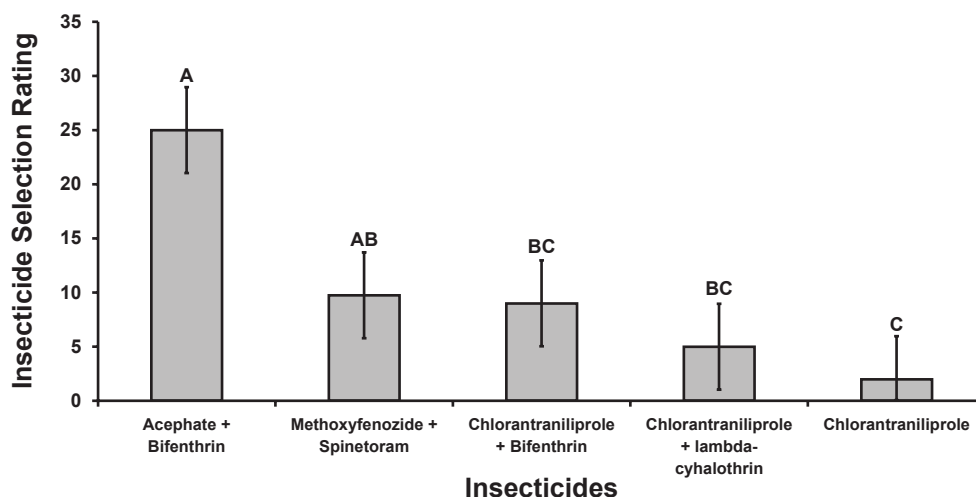


Figure 2. Insecticides recommended for bollworm control based on field efficacy and honey bee acute toxicity. Lower numbers equal greater bollworm control and lower honey bee toxicity. Higher numbers equal less bollworm control and greater honey bee toxicity. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

value from a control standpoint for the treatment of bollworm when applied alone. Pyrethroids such as lambda-cyhalothrin and bifenthrin are the primary drivers in honey bee toxicity in premix products with chlorantraniliprole (Besiege and Elevest) and it is not known if the effects are additive or synergistic. Chlorantraniliprole is in the diamide insecticide class, which is considered relatively harmless to beneficial arthropods (Lahm et al., 2005, 2009; Olivi, 2016). Diamides have a high level of residual efficacy against the targeted pest (Olivi, 2016; Villanueva and Walgenbach, 2005), and acute toxicity to worker honey bees appears to be low (Zhu et al., 2015). The study by Zhu et al. (2015) evaluated acute toxicity of various insecticides to adult worker honey bees only. That study did not include impacts on other life stages such as honey bee eggs, larvae or pupae. Chronic or behavioral changes were also not included in that study. However, honey bees exposed to chlorantraniliprole have been shown to exhibit long-lasting locomotor deficits, reduced survival, and impaired physiology (Kadala et al., 2019).

The presence of multiple pests in a field often requires mixing multiple insecticides to provide effective control. Currently, there is a limited number of insecticide classes available for pest management in agronomic crops making management difficult, especially when key pests are resistant to one or multiple classes. The impact of pests on yields can vary at different times of the year. For instance, yield losses from tarnished plant bugs are usually greater earlier in the flowering period than later in the flowering

period (Wood et al., 2016). As a result, pest managers might need to put more weight on pest efficacy during the early flowering period but can give more weight to honey bee toxicity later in the flowering period. Overall, these data form a concept and foundation for improving IPM by maximizing control of an important pest while considering pollinator health. Future research should focus on other pests in multiple crops and consider chronic toxicity or sublethal effects on honey bees and other pollinators.

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