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ARTHROPOD MANAGEMENT & APPLIED ECOLOGY

Evaluating the Effects of Excluding Various Insecticide Classes for Control of the Tarnished Plant Bug, *Lygus lineolaris* (Palisot De Beauvois), in ThryvOn Cotton, *Gossypium hirsutum* L.

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ABSTRACT

Assessments from the U.S. Environmental Protection Agency suggest that some insecticides can be affected by usage restrictions or label vacatur in the future. An experiment was conducted in Stoneville, Sidon, and Glendora, MS during 2023 to determine the effects of excluding insecticide classes for the control of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), on DP 2131 B3TXF ThryvOn cotton and DP 1646 B2XF cotton. Treatments were replicated in both the ThryvOn and non-ThryvOn varieties and included a season-long untreated control, all classes available for use, all classes except neonicotinoids, all classes except pyrethroids, all classes except organophosphates, and all classes except sulfoximines. Plots were scouted weekly to monitor tarnished plant bug densities and applications were made to plots independently using the best available insecticide options when each treatment reached established plant bug thresholds. Results indicated no significant differences in yield among exclusion class treatments in either variety. Significant reductions in yield were observed in the untreated control plots compared to plots that received insecticide intervention in both the ThryvOn and non-ThryvOn technologies. However, there were no significant differences between the economic returns of the untreated control plots compared to the plots receiving insecticide intervention in the ThryvOn technology. This evidence suggests that if insecticide usage is restricted from a single class, comparable yields can be achieved. However, it should be noted that any loss or reduction in insecticide usage currently used for tarnished plant bug control would result in increased selection pressure on the remaining insecticides, ultimately increasing resistance to those classes that remain available.

The U.S. Environmental Protection Agency (EPA) is the federal agency responsible for the approval and registration of pesticides in the U.S. Upon labeling a new insecticide, the EPA will periodically revisit the product to ensure it performs its intended function without unreasonable adverse effects on human health and the environment. This review process occurs approximately every 15 years and could arise sooner if sufficient evidence of environmental or human health harm is suspected. Currently, multiple organophosphates (acephate, dicrotophos, dimethoate), neonicotinoids (imidacloprid, thiamethoxam), and many other insecticides used for control of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), in cotton, *Gossypium hirsutum* L., are due for the review process, with all other products eventually undergoing this review process as well. If any insecticides currently used for the control of tarnished plant bugs in cotton receive usage restrictions or label vacatur (loss of registration), current management strategies for this pest might need to be altered.

The tarnished plant bug is the most economically important arthropod pest of cotton in the U.S. In 2022, this insect was responsible for an estimated loss of 98,525,924 kg of lint, as well as a combined cost of control plus yield losses totaling more than $324,000,000 (Cook et al., 2023). Cotton growers in the Mississippi Delta averaged 5.5 insecticide applications for the control of tarnished plant bugs with an estimated cost of $29.64 per application per hectare (Cook et al., 2023).

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Due to population suppression from frequent broad-spectrum insecticide applications targeting the cotton boll weevil, *Anthonomus grandis grandis* Boheman, and the tobacco budworm, *Chloridea virescens* (Fabricius), the tarnished plant bug historically has been a secondary pest of cotton (George et al., 2021; Musser et al., 2007). However, boll weevil eradication in the mid-southern U.S. and the development of transgenic cotton expressing *Bacillus thuringiensis* Berliner (Bt) insecticidal proteins led to fewer broad-spectrum foliar-applied insecticide applications, allowing the tarnished plant bug to emerge as a primary pest of cotton in the region (George et al., 2021; Gore et al., 2012; Musser et al., 2007; Stewart, 2003). A major component of the tarnished plant bug's significance in cotton is related to its destructive feeding habits, in which they feed on plant material by piercing the plant tissue, injecting salivary enzymes and other foreign compounds, and then extracting plant liquids (George et al., 2021). In cotton, tarnished plant bugs damage terminal growing points, squares, blooms, and small bolls (Stewart, 2003; Young, 1969). Due to their indeterminate growth habit, cotton plants possess these various stages of fruiting structures throughout a large portion of the growing season, allowing for continual damage to all structures from tarnished plant bug feeding (George et al., 2021; Musser et al., 2009). Plant bug feeding on terminal growing points can result in deformed cotton, referred to as stop-back, bushy top, or crazy cotton (George et al., 2021; Young, 1969). Damage to small squares can cause abscission, preventing the fruit from being harvested (George et al., 2021; Layton, 2000; Stewart, 2003). Feeding damage to larger squares might not result in abortion but instead cause buds to produce damaged flowers that are often discolored, deformed, display damaged anthers that result in poor pollination, and are referred to as dirty blooms (Gore et al., 2012; Layton, 1995; Pack and Tugwell, 1976). Tarnished plant bugs can also feed on and injure small bolls, resulting in boll malformation, stained lint, reduced lint quality, or boll abscission (Pack and Tugwell, 1976; Parencia, 1978; Russell, 1999).

Tarnished plant bugs can be partially managed through cultural practices such as planting date, variety selection, or controlling alternate hosts in nearby areas. However, the primary method for controlling tarnished plant bug populations in cotton is through foliar-applied insecticides. The most commonly used insecticides include organophosphates such as acephate (Orthene 90s, Amvac Chemical Company, Walnut Creek, CA) and dicrotophos (Bidrin 8E, Amvac Chemical Company), sulfoximines such as sulfoxaflor (Transform WG, Dow AgroSciences, Indianapolis, IN), pyrethroids such as bifenthrin (Fanfare EC, ADAMA USA, Raleigh, NC), and neonicotinoids such as thiamethoxam (Centric 40 WG, Syngenta Crop Protection, Greensboro, NC) and imidacloprid (Admire Pro 4,6SC, Bayer CropScience, Research Triangle Park, NC). Insect growth regulators including novaluron (Diamond 0.83 EC, ADAMA USA), are also commonly used for tarnished plant bug control. Although this insecticide does have some effect on adult female tarnished plant bug fecundity (Catchot et al., 2020), it must be combined with an adulticide to provide adequate control of adult tarnished plant bugs. Prolonged use of these insecticides has led to resistance in tarnished plant bug populations. Snodgrass et al., (2009) found increasing levels of acephate resistance from 2001 through 2007, as well as pyrethroid resistance in most of the acephate-resistance populations. It has also been found that tarnished plant bugs can develop some degree of tolerance during the growing season due to continuous insecticide exposure (George et al., 2021). Du et al. (2023) found that tarnished plant bugs collected in the fall in the Mississippi Delta exhibited a high resistance ratio to imidacloprid (up to 19.5-fold) and a moderate resistance to thiamethoxam (7.88-fold) as compared to a susceptible population. In a three-year study by Snodgrass and Scott (2000), pyrethroid resistance in tarnished plant bugs increased from spring to fall each year. This is likely attributed to the repeated applications of these insecticide classes throughout the year (Snodgrass and Scott, 2000). Current recommendations in Mississippi are to avoid applications of organophosphates and pyrethroids in cotton before first bloom to preserve their effectiveness for later use during the growing season (Crow et al., 2023).

A novel control method for tarnished plant bugs came from the commercialization of a transgenic cotton technology named ThryvOn® (Bayer CropScience, St. Louis, MO) expressing the *Bacillus thuringiensis kurstaki* (Bulla et al.) (Bt) protein MPP51Aa2. Historically, transgenic cotton varieties expressing insecticidal proteins derived from Bt have been used to control lepidopteran pests. However, ThryvOn cotton varieties have been developed for the control of tarnished plant bugs and various thrips species (Bachman et al., 2017). Research surrounding this technology has observed reduced tarnished plant bug densities compared to non-traited varieties managed similarly (Corbin et al., 2020; Graham et al., 2019; Mann et al., 2022). The findings by Graham et al. (2019) suggested that tarnished plant bugs infesting ThryvOn cotton might have increased susceptibility to insecticides due to the additional stress imposed by the Bt trait. Given these developments, we conducted field experiments to evaluate how excluding major insecticide classes affects tarnished plant bug management and cotton yield in ThryvOn vs. non-ThryvOn cotton. We hypothesized that excluding any single class of insecticide would not reduce yield when alternative classes remained but would increase the number of sprays needed (or lead to other changes). We also examined whether the ThryvOn trait modifies the need for insecticide inputs compared to conventional cotton.

MATERIALS AND METHODS

To evaluate the effects of excluding various insecticide classes for the control of tarnished plant bugs in ThryvOn and non-ThryvOn cotton, an experiment was conducted at the Delta Research and Extension Center in Stoneville, MS; on a commercial farm in Sidon, MS; and a commercial farm in Glendora, MS during the growing season of 2023. The experiment was conducted as a randomized complete block design with a factorial arrangement of treatments and four replications. Factor A was cotton technology, including the traited cultivar ThryvOn (DP 2131 B3TXF, Deltapine, Bayer Crop Science, St. Louis, MO), that expresses the MPP51Aa2 protein and a non-ThryvOn cotton variety (DP 1646 B2XF). Both cotton varieties were selected on the basis of genetic similarity to minimize variation between cotton varieties. Factor B consisted of insecticide class exclusion treatments that were initiated at first square and included (1) untreated control, (2) all classes (no insecticides excluded), (3) all classes except pyrethroids, (4) all classes except neonicotinoids, (5) all classes except organophosphates, and (6) all classes except sulfoximines. Individual insecticide applications made to each treatment at each location can be found in supplementary tables. Although insect growth regulators such as novaluron (IRAC group 15) are often used for tarnished plant bug control in cotton, they were not treated as an exclusion class due to their limited effectiveness on adult tarnished plant bugs.

Sampling was initiated at all locations in the first week of squaring. During the squaring stage, tarnished plant bug densities were determined by taking 25 sweeps per plot using a standard 38-cm diameter sweep net once per week. The tarnished plant bug threshold during the first two weeks of squaring in Mississippi is eight tarnished plant bugs per 100 sweeps or 20% square loss (i.e., retention < 80%; Crow et al., 2023). From the third week of squaring through bloom, the sweep net threshold increases to 15 tarnished plant bugs per 100 sweeps (Crow et al., 2023). Beginning at bloom, sampling methods shifted to taking two 0.76 by 0.91-m black drop cloth placements per plot per week (placed in the middle rows and shaken to dislodge bugs). Insecticide applications were warranted when the threshold of three tarnished plant bugs per 1.5 m (six bugs for the final week of bloom) per plot was reached (Crow et al., 2023). Additionally, due to fruit loss from cotton reaching the cutout stage, the square retention threshold was no longer used to trigger insecticide applications. Quantities of both tarnished plant bug nymphs and adults were recorded separately. Insecticide applications for tarnished plant bugs were made when the average number of adults and nymphs in each sampling method across all replications of a treatment met or exceeded current thresholds based on the 2023 Mississippi Insect Control Guide for Agronomic Crops (Crow et al., 2023). Insecticide applications were applied to plots that reached the economic threshold and selected based on relative efficacy with respect to their exclusion treatment. The untreated controls were left unsprayed for tarnished plant bugs throughout the growing season. Percentage of square retention was also calculated to aid in the determination of tarnished plant bug pressure throughout the season by examining the first-fruiting positions in each of the upper three nodes of plants within each plot for the presence or absence of squares until a total of 25 positions had been sampled. To be considered missing, the presence of an abscission scar (denoting fruit abortion) at the first position on each fruiting branch was observed, whereas blasted or flared squares can be characterized by being discolored, dried, or having the bracts flared open. Damaged squares were counted as missing as damaged squares will abscise and not result in harvestable fruit at that position. Following this procedure, the percentage of retained squares was calculated.

At the Stoneville, MS location, plots measured 12.19 m in length and 4.06 m in width. Both cotton varieties were planted at a seeding rate of approximately 112,000 seeds per hectare into conventionally tilled rows spaced 101.6 cm apart on 16 May 2023. Furrow irrigation was applied as needed. In Glendora and Sidon, MS, plots measured 12.19 m long and 3.86 m wide. Both cotton varieties were planted at a seeding rate of approximately 135,000 seeds per hectare into conventionally tilled rows spaced 96.52 cm apart on 24 May 2023 and 25 May 2023, respectively. Furrow irrigation was unavailable at these locations. Each location was kept weed-free using locally recommended preemergence and postemergence herbicides for control of problematic summer annual weeds. All varieties were treated with 0.375 mg imidacloprid per seed as a seed treatment to protect from early-season thrips injury. An application of methoxyfenozide + spinetoram (66.10 g a.i. + 13.56 g a.i. per ha, Intrepid Edge, Dow AgroSciences) was applied to all plots at each location during the seedling stage to suppress tobacco thrips (*Frankliniella fusca* [Hinds]) as thrips populations in the DP 1646 BG2XF variety are resistant to neonicotinoids. Additionally, because cotton bollworm (Helicoverpa zea [Boddie]) populations show resistance to Cry1Ac and Cry2Ab proteins, all plots at each location were treated with chlorantraniliprole (Vantacor, FMC Corporation, Philadelphia, PA) at a rate of 70.21g a.i. per ha for bollworm control in the DP 1646 BG2XF variety when needed. Plots were defoliated and mechanically harvested at the end of the growing season and seed cotton weights were recorded. Lint yield was determined by taking the seed cotton weight of each plot and multiplying it by 40%, a typical percentage lint turnout.

An economic analysis was performed to determine average input costs among treatments and their respective yield returns. To focus solely on input costs associated with tarnished plant bugs, the applications of methoxyfenozide + spinetoram (Intrepid Edge) and chlorantraniliprole (Vantacor) were excluded from the economic analysis. Input costs included seed, seed treatment, foliar-applied insecticides targeting tarnished plant bugs, and the costs of application. Seed and seed treatment costs were obtained from Bayer CropScience and set as the base costs for each variety. The cost for a bag (approximately 230,000 seeds) of 2131 B3TXF was $764, whereas the cost for a bag of 1646 B2XF was $674. Foliar-applied insecticide costs were obtained from local chemical suppliers (supplementary tables). The cost of application was calculated by taking the price of an aerial application and ground application found in the 2022 Cotton Insect Losses (Cook et al., 2023) and averaging those prices together to account for producers being able to use both methods. Income was determined by taking the current price per kilogram of lint cotton at the time of manuscript preparation, $2.05, and multiplying by the lint yields for each plot and averaging all plots within a treatment.

Data Analysis. Lint yield, number of insecticide applications targeting tarnished plant bugs, and economic data were each analyzed using a general linearized mixed model analysis of variance (Proc Glimmix, SAS Version 9.4, SAS Institute Inc. Cary, NC). Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using LSMEANS and separated based on Fisher's protected least significant difference (LSD) (α = 0.05). The Proc Means procedure was used to estimate the means and standard errors of the means. Due to the varying yield potentials between the two varieties, the lint yield data and economic returns data were analyzed by variety. In these analyses, treatment was considered a fixed effect, with location and replication nested within location considered random effects. In the insecticide application analysis, treatment, variety, and the interaction of treatment by variety were considered fixed effects, with location considered a random effect.

Due to varying thresholds for the two sampling methods used, tarnished plant bug numbers were converted to a percentage of threshold as a way of standardizing the data throughout the season. This percentage of threshold was calculated by taking the total number of tarnished plant bugs sampled and dividing by the current threshold for the respective sampling method. Tarnished plant bug densities recorded throughout the season, expressed as percentage of threshold, were analyzed to determine pressure amongst treatments. Square retention was expressed as a percentage of the retained fruit of the sampled fruiting sites. Tarnished plant bug percent threshold and percent square retention data 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). Due to variations in tarnished plant bug infestations, each location was analyzed separately. Additionally, due to ThryvOn expressing a Bt protein with suppression activity against tarnished plant bug, each variety was analyzed individually. In the percent threshold and percent square retention analyses, treatment, week of sample, and treatment by week of sample were considered the fixed effects, with replication considered a random effect. Week of sample was considered the repeated measure. The Kenward-Rogers method was used to calculate the degrees of freedom. Means were calculated using LSMEANS and separated based on Fisher's protected least significant difference (LSD) (α = 0.05). The Proc Means procedure was used to calculate the means and standard errors of the means. In the percent square retention analysis for the non-ThryvOn variety at the Sidon location, the repeated measure model could not form valid estimates. Therefore, the non-ThryvOn variety at this location was analyzed using a general linearized mixed model analysis of variance (Proc Glimmix, SAS Version 9.4, SAS Institute Inc. Cary, NC). In this analysis, treatment, week of sample, and treatment by week of sample were set as fixed effects, with replication as the random effect. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using LSMEANS and separated based on Fisher's protected LSD (α = 0.05). The Proc Means procedure was used to calculate the means and standard errors of the means.

RESULTS

Combined. Due to the untreated control receiving no insecticide applications for control of tarnished plant bugs throughout the growing season, it was excluded from the insecticide application analysis. There was no significant interaction between variety and treatment (F = 1.82; df = 4, 18; $p = 0.17$). Significant differences were observed in the number of insecticide applications targeting tarnished plant bugs between treatments (F = 3.09; df = 4, 18; $p = 0.04$) and varieties (F = 20.45; df = 1, 18; $p < 0.01$). In the non-ThryvOn variety, the no pyrethroids treatment averaged significantly less insecticide applications targeting tarnished plant bugs than the no exclusions or no organophosphates treatments (Table 1). There were no significant differences in the number of insecticide applications between treatments within the ThryvOn variety (Table 1). Additionally, treatments in the ThryvOn variety received an average of 2.07 (± 0.25) insecticide applications targeting tarnished plant bugs throughout the growing season, whereas the non-ThryvOn treatments received an average of 3.07 (± 0.28) insecticide applications (Fig. 1).

In the economic analysis, all treated plots in the non-ThryvOn variety had significantly higher returns compared to the untreated control (Table 2). Within the ThryvOn variety, there were no significant differences between any treatment (Table 2). Across all treatments, the ThryvOn variety averaged $1,186.95 (± 38.08) net income per hectare compared to the non-ThryvOn average of $890.76 (± 45.90) per hectare (Fig. 2).

Non-ThryvOn (DP 1646). In the percent threshold analyses at the Glendora location, there was a significant treatment by week interaction (F = 2.28; df = 30, 69.81; $p < 0.01$). No significant differences were observed between treatments within the first, second, third, or fourth weeks of sampling (Fig. 3). However, the no exclusions treatment reached threshold in the first week of sample. All tarnished plant bug densities in plots for all other treatments were above threshold in the second and third weeks of sampling. Plots in all treatments excluding the untreated control were below threshold in the fourth week of sampling. In the fifth week of sampling, the untreated control plots had significantly higher tarnished plant bug densities than all treated plots,

Table 1. Mean (SEM) number of insecticide applications for each variety across all locations

Treatment	Non-ThryvOn (DP 1646)	ThryvOn (DP 2131)
	------------------------------- Number of Applications	-------------------------------
No Exclusions	**3.33 (0.88) ab**	**2 (1.0) cd**
No Organophosphates	**4 (0.0) ab**	**2.33 (0.33) bcd**
No Pyrethroids	**2 (0.58) cd**	**2 (0.58) cd**
No Neonicotinoids	**3 (0.58) abc**	**1.67 (0.67) d**
No Sulfoximines	**3 (0.58) abc**	**2.33 (0.33) bcd**

Means followed by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). Treatment (F = 3.09; df = 4, 18; $p = 0.04$). Variety (F = 20.45; df = 1, 18; $p < 0.01$). Treatment*Variety Interaction (F = 1.82; df = 4, 18; $p = 0.17$).

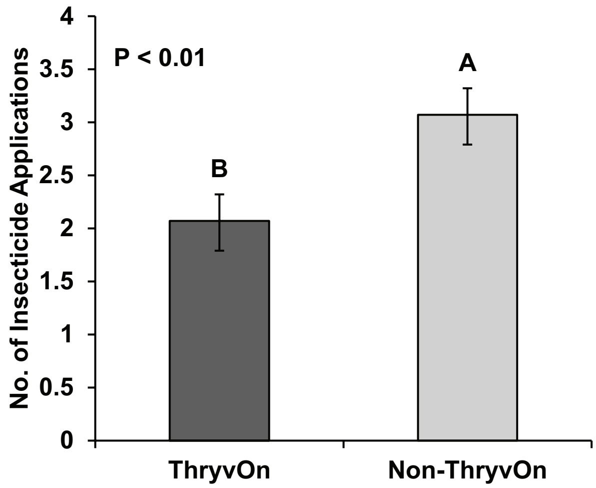

Figure 1. Mean number of tarnished plant bug insecticide applications by variety. Bars with different letters are significantly different using Fisher's Protected LSD (α = 0.05). (F = 14.13; df = 1, 26; *p* < 0.01).

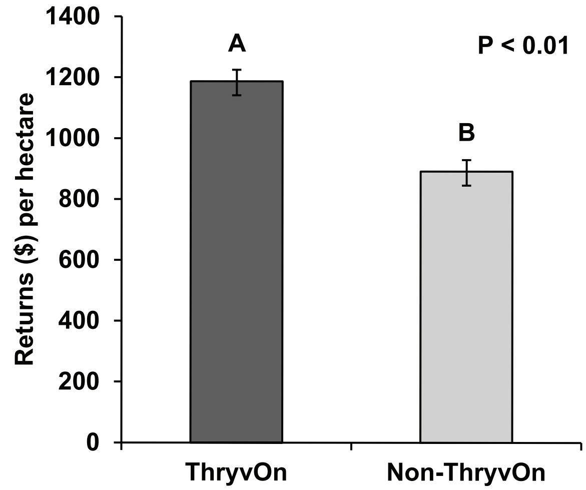

Figure 2. Mean economic returns over specified costs per hectare by variety. Bars with different letters are significantly different using Fisher's Protected LSD (α = 0.05). (F = 37.90; df = 1, 140; *p* < 0.01). Means averaged across all locations.

Table 2. Mean (SEM) economic returns for each variety across all locations

Treatment	Non-ThryvOn (DP 1646)	ThryvOn (DP 2131)
	---------- $ ha^{-1} ----------	
UTC	506.92 (177.93) b	1121.85 (135.25) a
No Exclusions	1044.65 (125.31) a	1221.61 (121.81) a
No Organophosphates	1019.29 (54.07) a	1279.16 (144.33) a
No Pyrethroids	1007.87 (112.40) a	1222.17 (74.07) a
No Neonicotinoids	1115.95 (163.98) a	1278.93 (121.32) a
No Sulfoximines	971.54 (124.75) a	1207.28 (130.01) a
F	7.74	0.99
df	5, 15	5, 15
p	<0.01	0.46

Means followed by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

excluding the no exclusions treatment. Within this week, only plots in the no pyrethroids and no sulfoximines treatments were below threshold. In the sixth week of sampling, there were no significant differences in percent threshold between plots in the untreated control and the no organophosphates, no sulfoximines, or no exclusions treatments. Tarnished plant bug densities in plots in the no pyrethroids and no neonicotinoids treatments were significantly lower than the untreated control. Additionally in this week of sampling, plots in all treatments were at threshold excluding the no pyrethroids treatment. In the seventh week of sampling, plots in the no organophosphates and no exclusions treatments were significantly lower than plots in the untreated control and no pyrethroid treatments.

At the Sidon location, there was a significant interaction between treatment and week of sample (F = 2.58; df = 35, 79.52; *p* < 0.01). There were no significant differences in percent threshold between treatments within the first, second, third, fourth, and fifth weeks of sampling (Fig. 4). Plots in the no organophosphates, no neonicotinoids, no sulfoximines, and no exclusions treatments reached threshold in the second week of sampling. Plots in the no organophosphates and no neonicotinoids treatments reached threshold in the fourth week of sampling. Plots in the no sulfoximines and no exclusions treatments reached threshold in the fifth week of sampling. In the sixth week of sampling, plots in the untreated control, no organophosphates, and no pyrethroids treatments had significantly higher tarnished plant

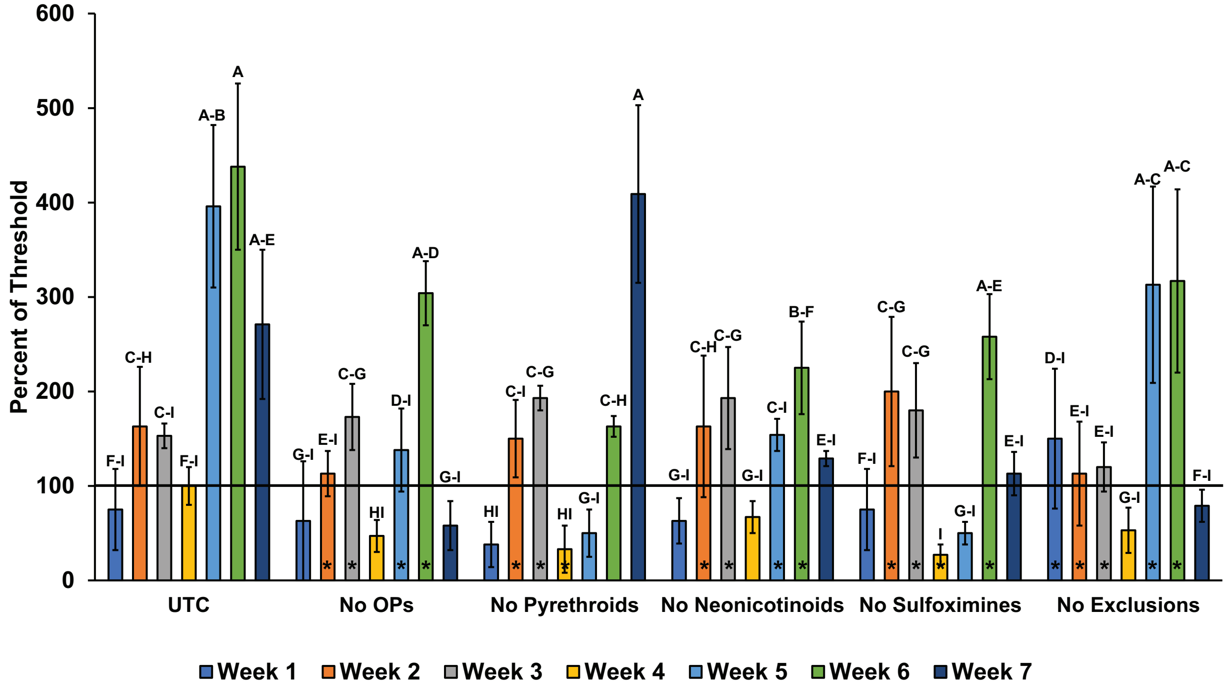

Figure 3. Percent TPB threshold in the non-ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: F = 3.91; df = 5, 101.7; $p < 0.01$) (Week: F = 21.51; df = 6, 48.35; $p < 0.01$) (Week*Treatment: F = 2.28; df = 30, 69.81; $p < 0.01$). Asterisks indicate an insecticide application was made to control tarnished plant bugs during that week of sample based on economic thresholds. Solid black line indicates the current action threshold (100%) for reference across the figure.

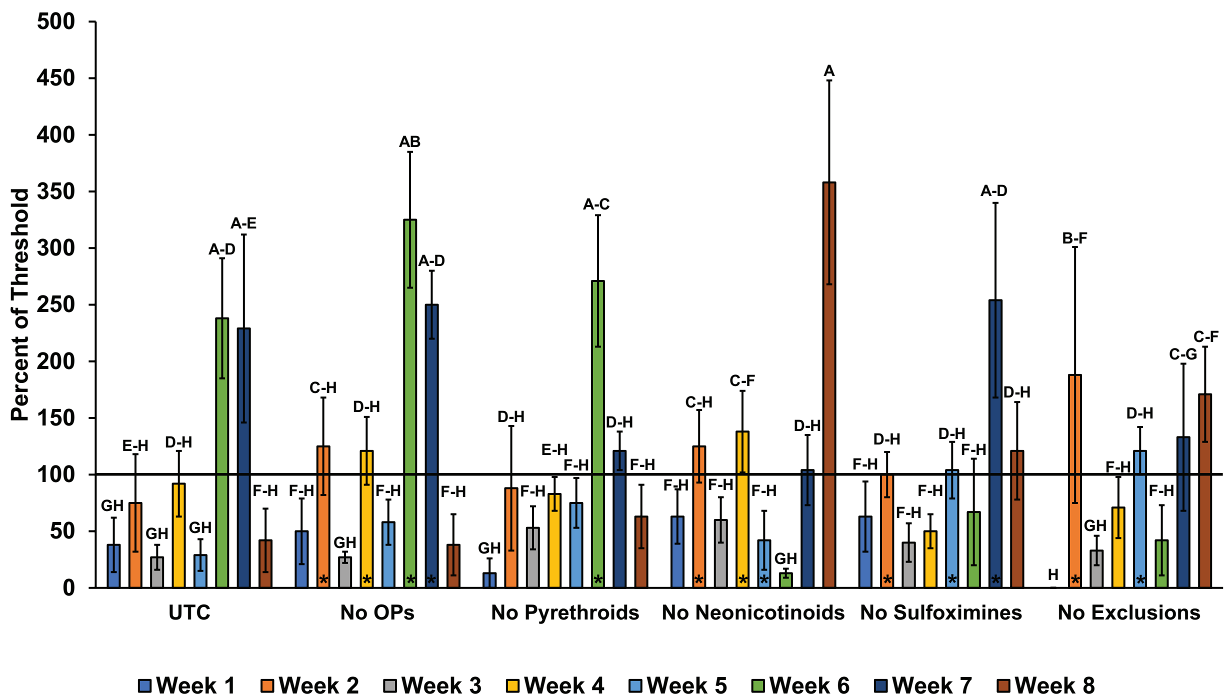

Figure 4. Percent TPB threshold in the non-ThryvOn variety at the Sidon, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: F = 0.64; df = 5, 89.31; $p = 0.67$) (Week: F = 12.90; df = 7, 53.88; $p < 0.01$) (Week*Treatment: F = 2.58; df = 35, 79.52; $p < 0.01$). Asterisks indicate an insecticide application was made to control tarnished plant bugs during that week of sample based on economic thresholds. Solid black line indicates the current action threshold (100%) for reference across the figure.

bug pressure than plots in the no neonicotinoids, no sulfoximines, and no exclusions treatments. Additionally in this week, plots in the untreated control, no organophosphates, and no pyrethroid treatments were all above threshold. In the seventh week of sampling, there were no significant differences between treatments. However, plots in the untreated control, no organophosphates, and no sulfoximines treatments were above threshold. In the eighth week of sampling, plots in the no neonicotinoids treatment had significantly higher tarnished plant bug pressure than all other treatments.

At the Stoneville location, there was a significant interaction between treatment and week of sample (F = 2.29; df = 35, 17.76; $p < 0.01$). No significant difference in percent threshold was observed between plots in any treatments within the first, second, third, fourth, fifth, or sixth weeks of sampling (Fig. 5). Plots in the no exclusions and no neonicotinoids treatments were at or above threshold in the first week of sampling. Plots in the untreated control and the no sulfoximines treatments were at or above threshold in the third week of sampling. Plots in the no organophosphates and no exclusions treatments were above threshold in the fourth week of sampling. Plots in the untreated control, no pyrethroids, no neonicotinoids, and no sulfoximines treatments were at threshold in the fifth week of sampling. Also in this week, an insecticide application was made to plots in the no exclusions treatment, which was at 2.9 tarnished plant bugs per 1.5 m. Plots in the untreated control were above threshold in the sixth week of sampling. In the seventh week of sampling, plots in the untreated control had significantly higher tarnished plant bug density compared to plots in all other treatments. Additionally, plots in the untreated control, no organophosphates, and no pyrethroids treatments were above threshold at this sample.

In the percent square retention analysis at the Glendora location, there was no significant interaction between treatment and week of sampling (F = 1.35; df = 30, 70.97; $p = 0.15$). However, treatment (F = 6.79; df = 5, 94.38; $p < 0.01$) and week of sampling (F = 14.28; df = 6, 49.13; $p < 0.01$) were significant. Plots in the no pyrethroids treatment had significantly lower percent square retention compared to plots in the no neonicotinoids and no sulfoximines treatments (Fig. 6). Percent square retention in the untreated control plots was significantly lower than plots in all other treatments. Additionally, week three had sig-

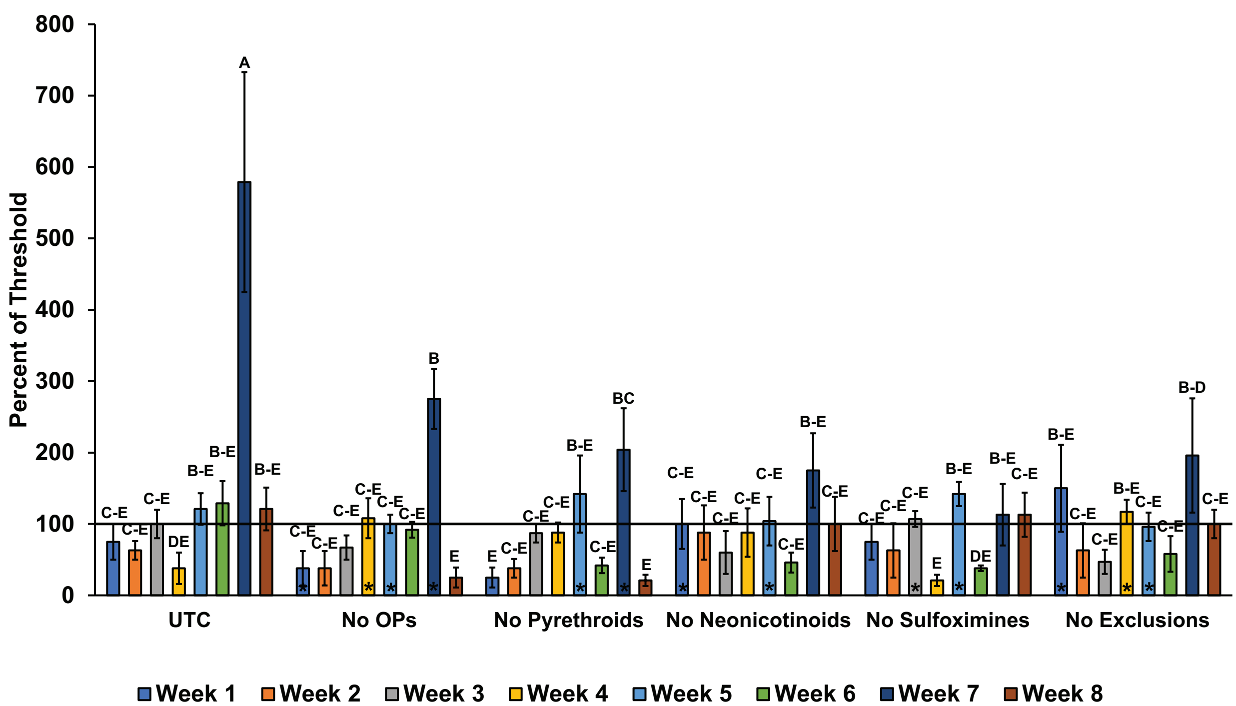

Figure 5. Percent TPB threshold in the non-ThryvOn variety at the Stoneville, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 4.34; df = 5, 53.93; $p < 0.01$) (Week: F = 6.13; df = 7, 51.66; $p < 0.01$) (Week*Treatment: F = 2.29; df = 35, 77.76; $p < 0.01$). Asterisks indicate an insecticide application was made to control tarnished plant bugs during that week of sample based on economic thresholds. Solid black line indicates the current action threshold (100%) for reference across the figure.

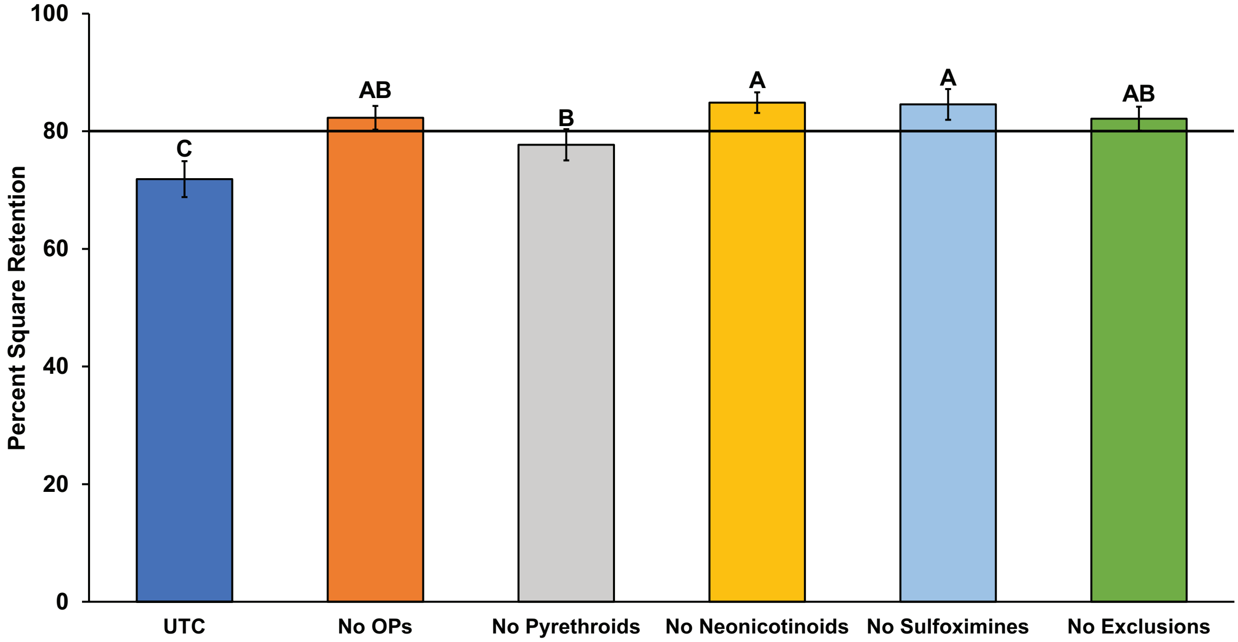

Figure 6. Percent square retention by treatment in the non-ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 6.79; df = 5, 94.38; p < 0.01) (Week: F = 14.28; df = 6, 49.13; p < 0.01) (Week*Treatment: F = 1.35; df = 30, 70.97; p = 0.15). Solid black line indicates the current action threshold (80%) for reference across the figure.

nificantly lower percent square retention compared to all other weeks (Fig. 7). Percent square retention in weeks one and five was significantly higher than all other weeks.

In the percent square retention analysis at the Sidon location, there was no interaction between treatments and week of sampling (F = 0.82; df = 35, 141; p = 0.74). However, both treatment (F = 3.55; df = 5, 141; p < 0.01) and week of sampling (F = 18.09; df = 7, 141; p < 0.01) were significant. Across treatments, plots in the untreated control had significantly lower percent square retention than all treated plots (Fig. 8). Percent square retention in week one was significantly higher than all other weeks (Fig. 9). Percent square retention in week two was higher than in weeks four, five, seven, or eight. Square retention in week eight was significantly lower than all other weeks.

At the Stoneville location, there was no significant interaction between treatment and week of sampling (F = 1.43; df = 35, 79.54; p = 0.10). However, treatment (F = 4.06; df = 5, 71.92; p < 0.01) and week of sampling (F = 17.01; df = 7, 52.52; p < 0.01) were significant. Percent square retention in the untreated control plots was significantly lower than all other treatments (Fig. 10). Percent square retention in the sixth week was higher than in weeks one, two, five, seven, and eight (Fig. 11). Square retention in week eight was significantly lower than in all other weeks.

In the lint yield analysis, there were no significant differences between treated plots in the non-ThryvOn variety across all locations (Table 3). All treated plots yielded significantly higher than the untreated control.

ThryvOn (DP 2131). In the percent threshold analysis at the Glendora location, there was a significant interaction between treatment and week of sampling (F = 2.29; df = 30, 71.2; p < 0.01). There were no significant differences in percent threshold within the first, second, third, fourth, sixth, or seventh weeks of sampling (Fig. 12). In the first week of sampling, plots in the untreated control, no neonicotinoids, and no exclusions treatments were above threshold. In the second week of sampling, plots in the untreated control, no organophosphates, no pyrethroids, no sulfoximines, and no exclusions treatments were above threshold. In the third week of sampling, plots in all treatments were above threshold. In the fourth week of sampling, only the untreated control plots were above threshold. In the fifth week of sampling, the untreated control plots had significantly higher tarnished plant bug density compared to all treated plots. Additionally, plots in the untreated control, no pyrethroids, no sulfoximines, and no exclusions

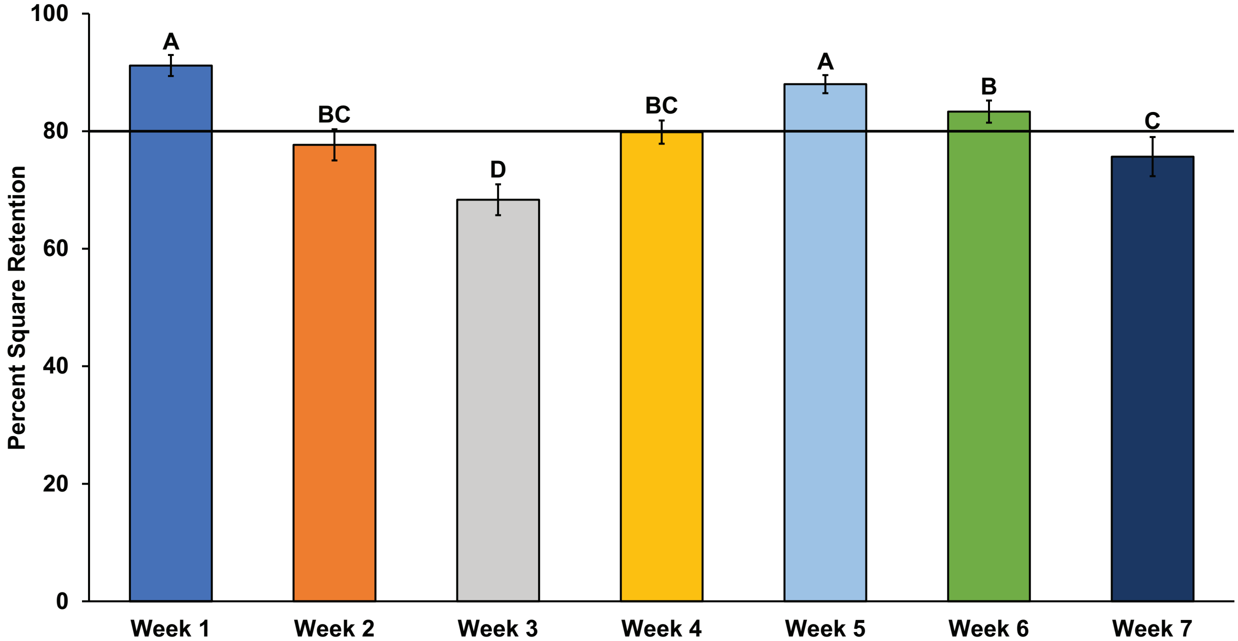

Figure 7. Percent square retention by week of sample in the non-ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: $F = 6.79$; df = 5, 94.38; $p < 0.01$) (Week: $F = 14.28$; df = 6, 49.13; $p < 0.01$) (Week*Treatment: $F = 1.35$; df = 30, 70.97; $p = 0.15$). Solid black line indicates the current action threshold (80%) for reference across the figure.

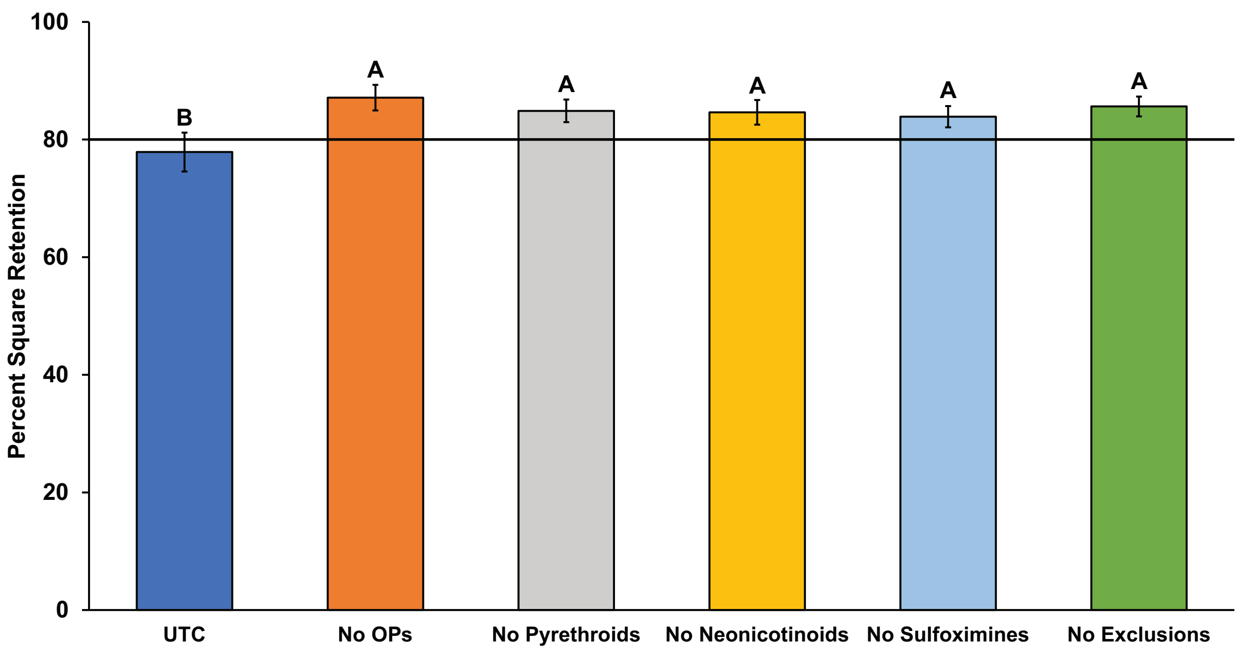

Figure 8. Percent square retention by treatment in the non-ThryvOn variety at the Sidon, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: $F = 3.55$; df = 5, 141; $p < 0.01$) (Week: $F = 18.09$; df = 7, 141; $p < 0.01$) (Week*Treatment: $F = 0.82$; df = 35, 141; $p = 0.74$). Solid black line indicates the current action threshold (80%) for reference across the figure.

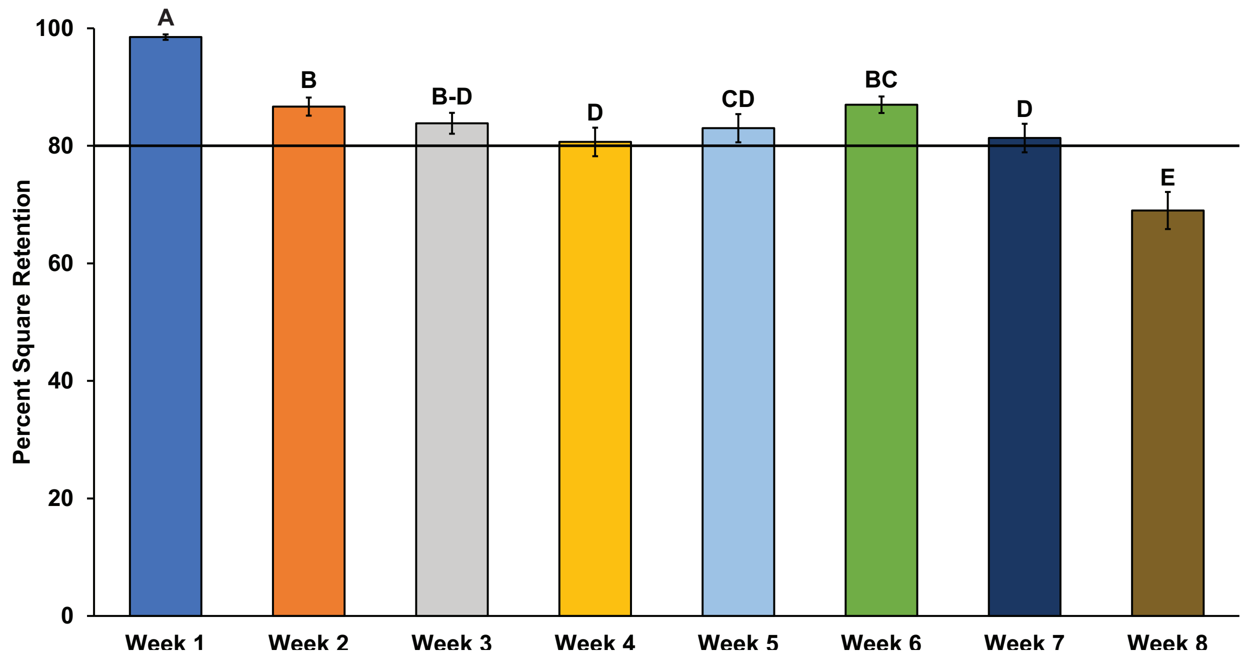

Figure 9. Percent square retention by week of sample in the non-ThryvOn variety at the Sidon, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 3.55; df = 5, 141; p < 0.01) (Week: F = 18.09; df = 7, 141; p <0.01) (Week*Treatment: F = 0.82; df = 35, 141; p = 0.74). Solid black line indicates the current action threshold (80%) for reference across the figure.

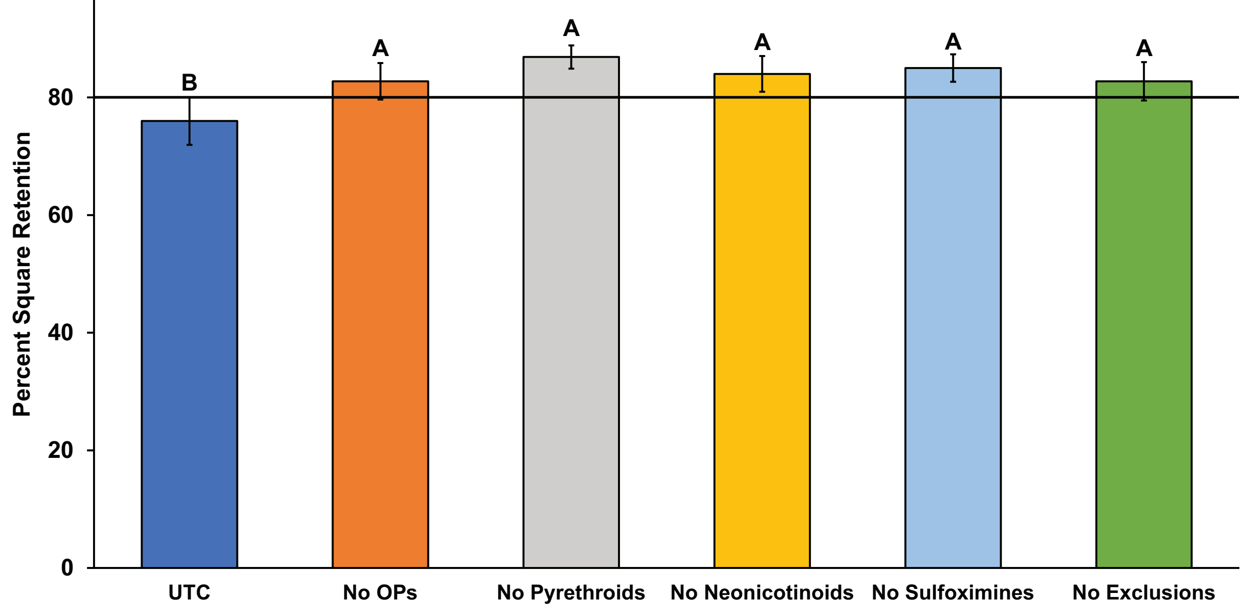

Figure 10. Percent square retention by treatment in the non-ThryvOn variety at the Stoneville, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 4.06; df = 5, 71.92; p < 0.01) (Week: F = 17.01; df = 7, 52.52; p < 0.01) (Week*Treatment: F = 1.43; df = 35, 79.54; p = 0.10). Solid black line indicates the current action threshold (80%) for reference across the figure.

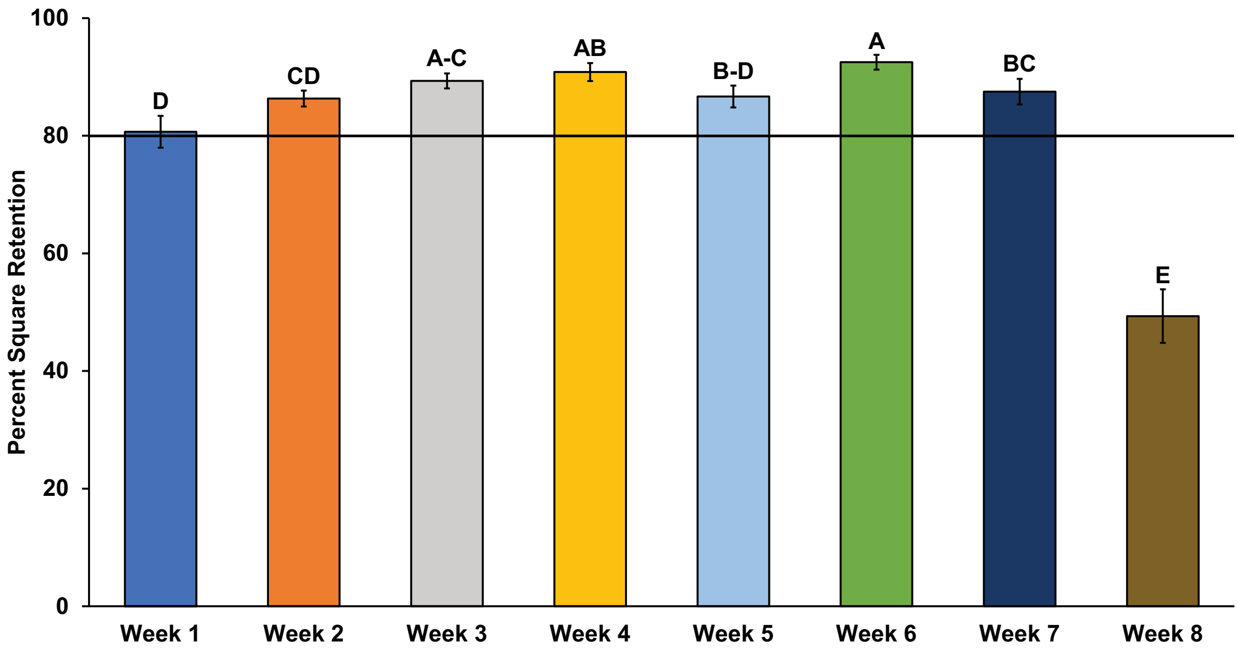

Figure 11. Percent square retention by week of sample in the non-ThryvOn variety at the Stoneville, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: F = 4.06; df = 5, 71.92; $p < 0.01$) (Week: F = 17.01; df = 7, 52.52; $p < 0.01$) (Week*Treatment: F = 1.43; df = 35, 79.54; $p = 0.10$). Solid black line indicates the current action threshold (80%) for reference across the figure.

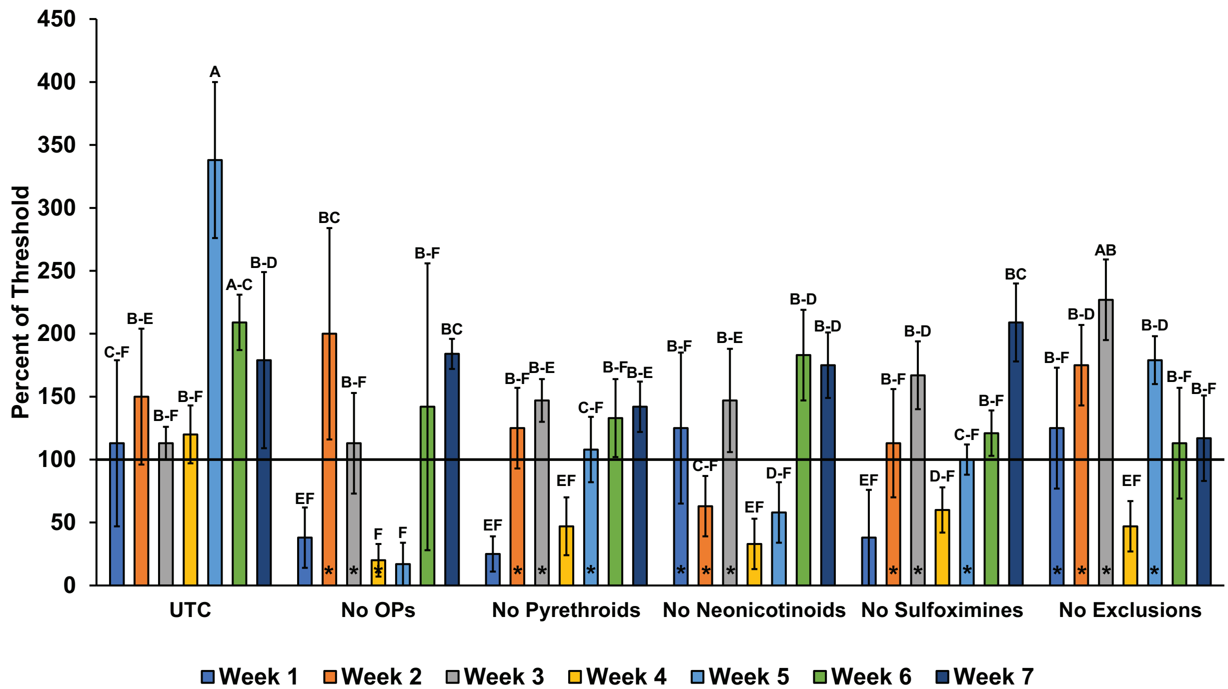

Figure 12. Percent TPB threshold in the ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: F = 3.56; df = 5, 94.82; $p < 0.01$) (Week: F = 12.71; df = 6, 49.08; $p < 0.01$) (Week*Treatment: F = 2.29; df = 30, 71.2; $p < 0.01$). Asterisks indicate an insecticide application was made to control tarnished plant bugs during that week of sample based on economic thresholds. Solid black line indicates the current action threshold (100%) for reference across the figure.

treatments were at or above threshold. In the sixth week of sampling, the untreated control plots were the only plots at or above threshold.

At the Sidon location, treatment (F = 1.76; df = 5, 62.37; p = 0.13) and the interaction between treatment and week of sampling (F = 1.11; df = 35, 79.70; p = 0.34) were not significant. However, week of sampling was significant (F = 19.75; df = 7, 54.11; p < 0.01). Tarnished plant bug density expressed as a percentage of threshold was significantly higher in week six compared to all other weeks (Fig. 13). Tarnished plant bug percent threshold was also higher in weeks two and seven compared to weeks one, three, four, and five.

At the Stoneville location, there was a significant interaction between treatment and week of sampling (F = 2.29; df = 35, 77.91; p < 0.01). No significant differences in percent threshold were observed within weeks for the first, second, third, fourth, and fifth weeks of sampling (Fig. 14). Plots in the no sulfoximines treatment reached threshold in the first week of sampling. No plots in any treatment reached threshold in the second or third weeks of sampling. Plots in the no organophosphates and no pyrethroids treatments reached threshold in the fourth week of sampling. Plots in the no neonicotinoids and no sulfoximines treatments reached threshold in the fifth week of sampling. Also, within this week insecticide applications were made to the no organophosphates and no exclusions treatments, which were at 2.9 tarnished plant bugs per 1.5m. In the sixth and seventh weeks of sampling, the untreated control plots were the only plots to reach threshold.

In the percent square retention analysis for the Glendora location, there was no interaction between treatment and week of sampling (F = 1.04; df = 30, 71.55; p = 0.44). However, treatment (F = 6.76; df = 5, 83.62; p < 0.01) and week of sampling (F = 15.06; df = 6, 49.18; p < 0.01) were significant. Percent square retention in the untreated control plots was significantly lower than in all other treatments (Fig. 15). Additionally, percent square retention was significantly lower in week three compared to all other weeks (Fig. 16). Square retention in weeks one and five was significantly higher than all other weeks excluding week six.

In the square retention analysis for the Sidon location, treatment (F = 0.73; df = 5, 89.58; p = 0.60) and the interaction between treatment and week of sampling (F = 0.93; df = 35, 72.19; p = 0.59) were not significant. However, week of sampling was significant (F = 26.27; df = 7, 50.81; p < 0.01). Percent square retention in week eight was significantly lower than all other treatments excluding week seven

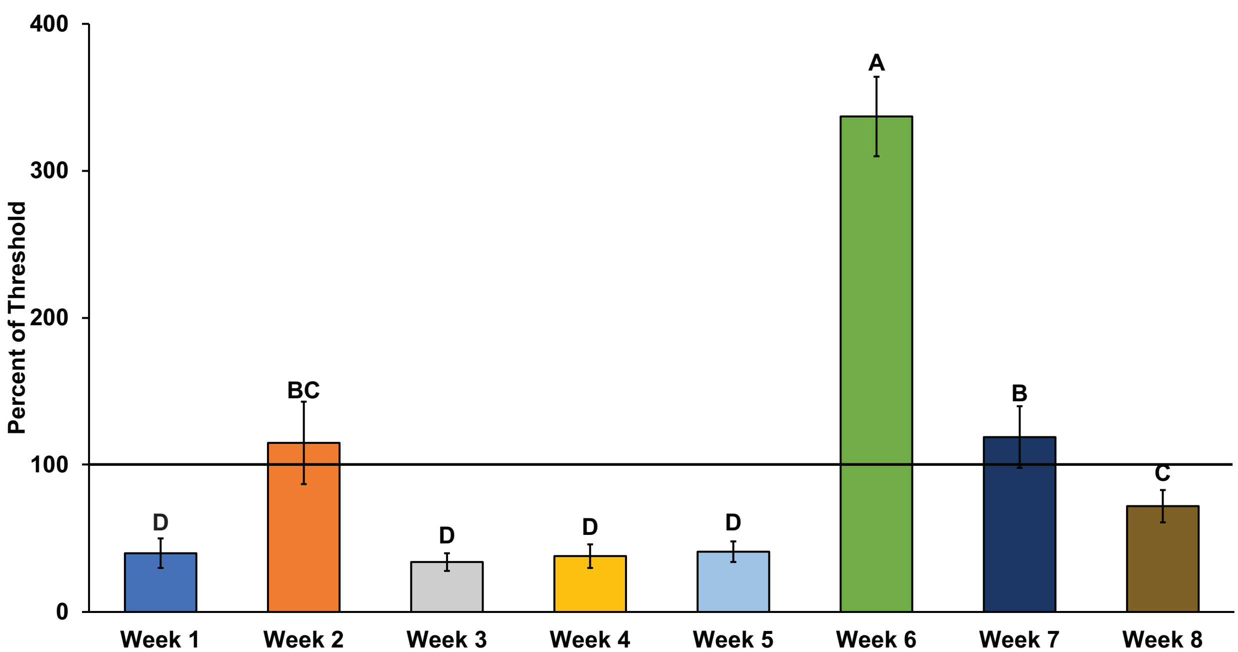

Figure 13. Percent TPB threshold by week of sample in the ThryvOn variety at the Sidon, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 1.76; df = 5, 62.37; p = 0.13) (Week: F = 19.75; df = 7, 54.11; p < 0.01) (Week*Treatment: F = 1.11; df = 35, 79.7; p = 0.34). Solid black line indicates the current action threshold (100%) for reference across the figure.

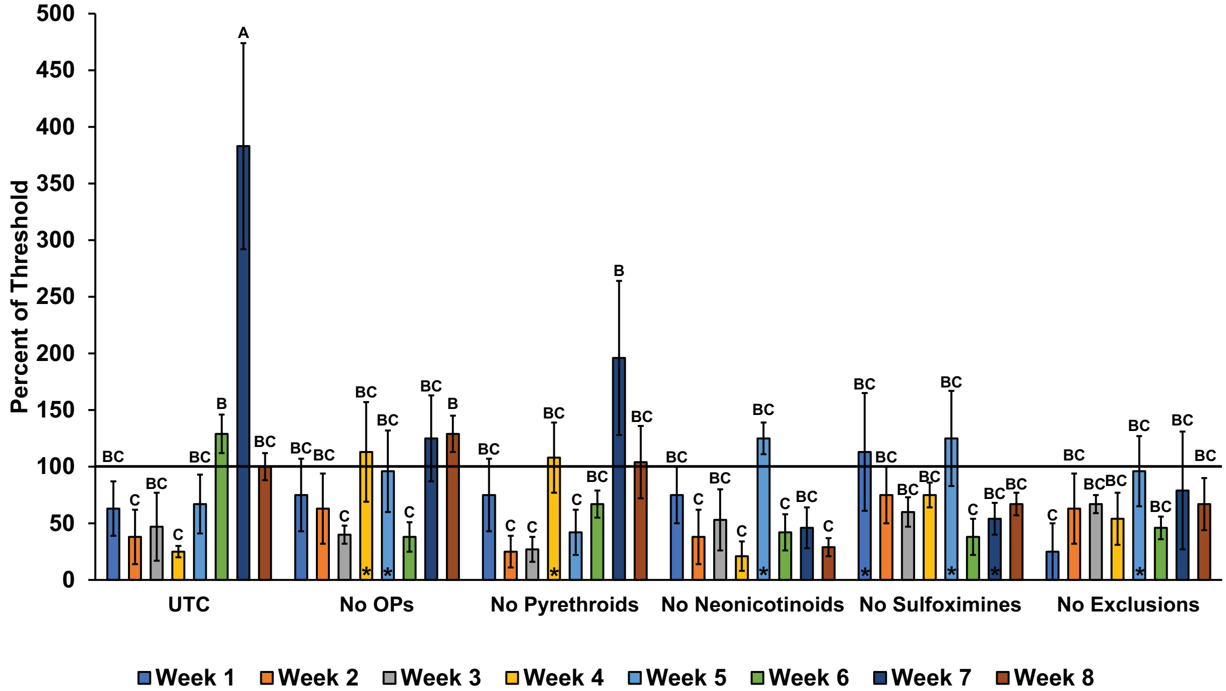

Figure 14. Percent TPB threshold in the ThryvOn variety at the Stoneville, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: $F = 4.34$; df = 5, 54.09; $p < 0.01$) (Week: $F = 6.07$; df = 7, 51.69; $p < 0.01$) (Week*Treatment: $F = 2.29$; df = 35, 77.81; $p < 0.01$). Asterisks indicate an insecticide application was made to control tarnished plant bugs during that week of sample based on economic thresholds. Solid black line indicates the current action threshold (100%) for reference across the figure.

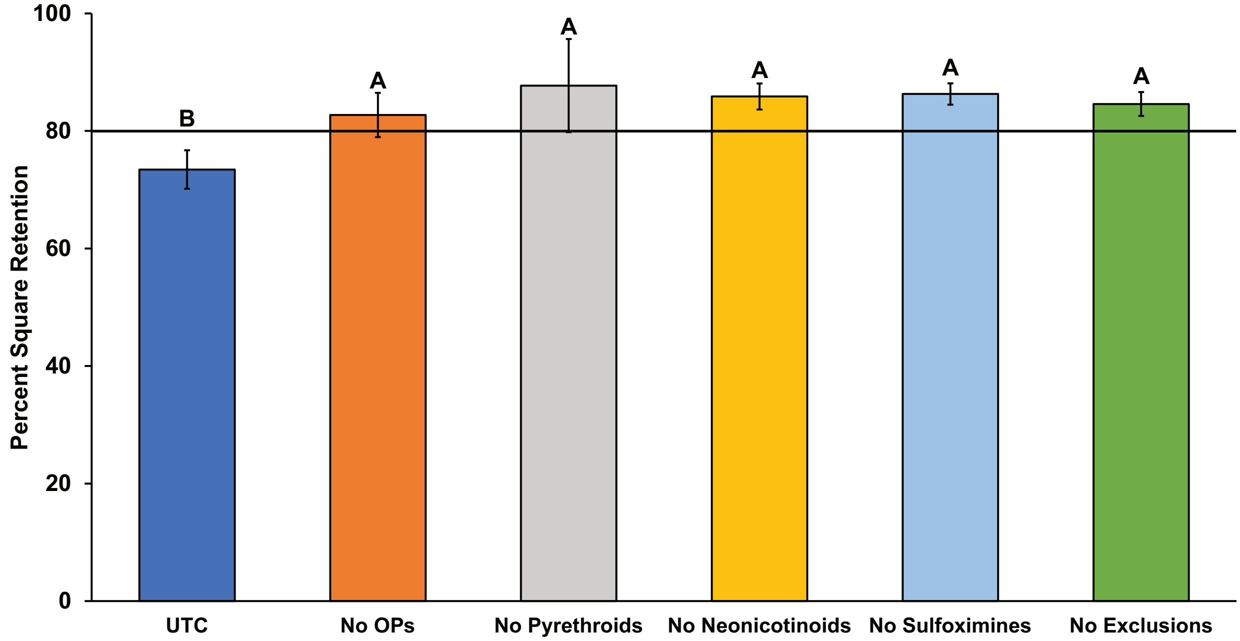

Figure 15. Percent square retention by treatment in the ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$). (Treatment: $F = 6.76$; df = 5, 83.62; $p < 0.01$) (Week: $F = 15.06$; df = 6, 49.18; $p < 0.01$) (Week*Treatment: $F = 1.04$; df = 30, 71.55; $p = 0.44$). Solid black line indicates the current action threshold (80%) for reference across the figure.

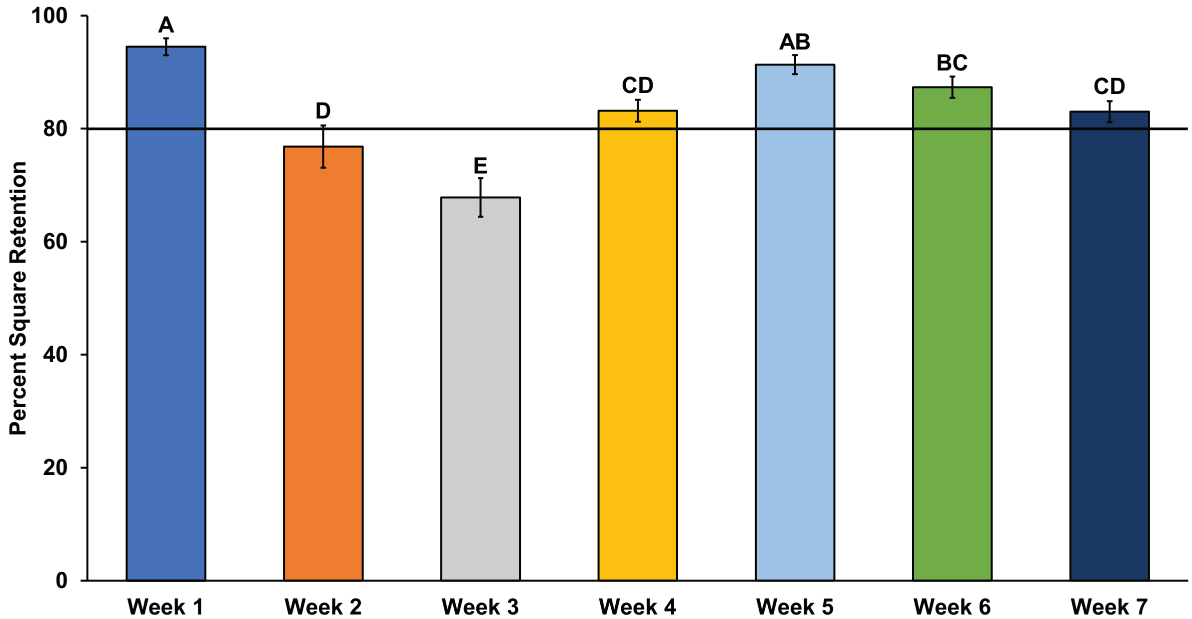

Figure 16. Percent square retention by week of sample in the ThryvOn variety at the Glendora, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 6.76; df = 5, 83.62; *p* < 0.01) (Week: F = 15.06; df = 6, 49.18; *p* < 0.01) (Week*Treatment: F = 1.04; df = 30, 71.55; *p* = 0.44). Solid black line indicates the current action threshold (80%) for reference across the figure.

(Fig. 17). Square retention in week one was significantly higher than all other weeks.

At the Stoneville location, treatment (F = 0.90; df = 5, 52.16; $p = 0.49$) and the interaction between treatment and week of sampling were not significant (F = 0.51; df = 35, 83.64; $p = 0.99$). However, week of sampling was significant (F = 21.94, df = 7, 56.49; $p < 0.01$). Percent square retention in week eight was significantly lower than in all other weeks (Fig. 18). Percent square retention in weeks four, five, and six were significantly higher than in week seven.

In the lint yield analysis, there were no significant differences between treated plots in the ThryvOn variety across all locations (Table 3). All treated plots yielded significantly higher than the untreated control plots (Table 3).

DISCUSSION

In both the ThryvOn and non-ThryvOn varieties, excluding any single insecticide class, while allowing others, did not significantly reduce lint yield in the treated plots. However, untreated non-ThryvOn plots suffered significantly reduced economic returns compared to the insecticide treated plots. These data suggest that the singular loss of any insecticide class will not result in an immediate significant yield loss in the mid-southern U.S. However, the loss of any insecticide class commonly used for tarnished plant bug control will result in increased selection pressure on any remaining classes, as there will be a reduction in potential rotational robustness.

There are four primary insecticide classes commonly recommended for tarnished plant bug control during bloom in the mid-southern U.S.: organophosphates, pyrethroids, sulfoximines, and insect growth regulators (chitin synthesis inhibitors). However, due to the observed level of control, these products are often recommended as tank-mixes, not four separate, stand-alone control options. In Mississippi, these mixes are often an organophosphate mixed with a neonicotinoid (e.g., acephate + imidacloprid), an organophosphate mixed with a pyrethroid (e.g., acephate/dicrotophos + bifenthrin/lambda cyhalothrin), a sulfoximine mixed with an IGR (e.g., sulfoxaflor + novaluron), or a sulfoximine mixed with an organophosphate (e.g., sulfoxaflor + acephate). Neonicotinoids are primarily used pre-bloom in cotton and are not recommended for the control of tarnished plant bugs once bloom begins due to poor product performance during this window. This places cotton producers in a situation where, although the loss of any insecticide class might not have immediate negative impacts on plant bug management or yield,

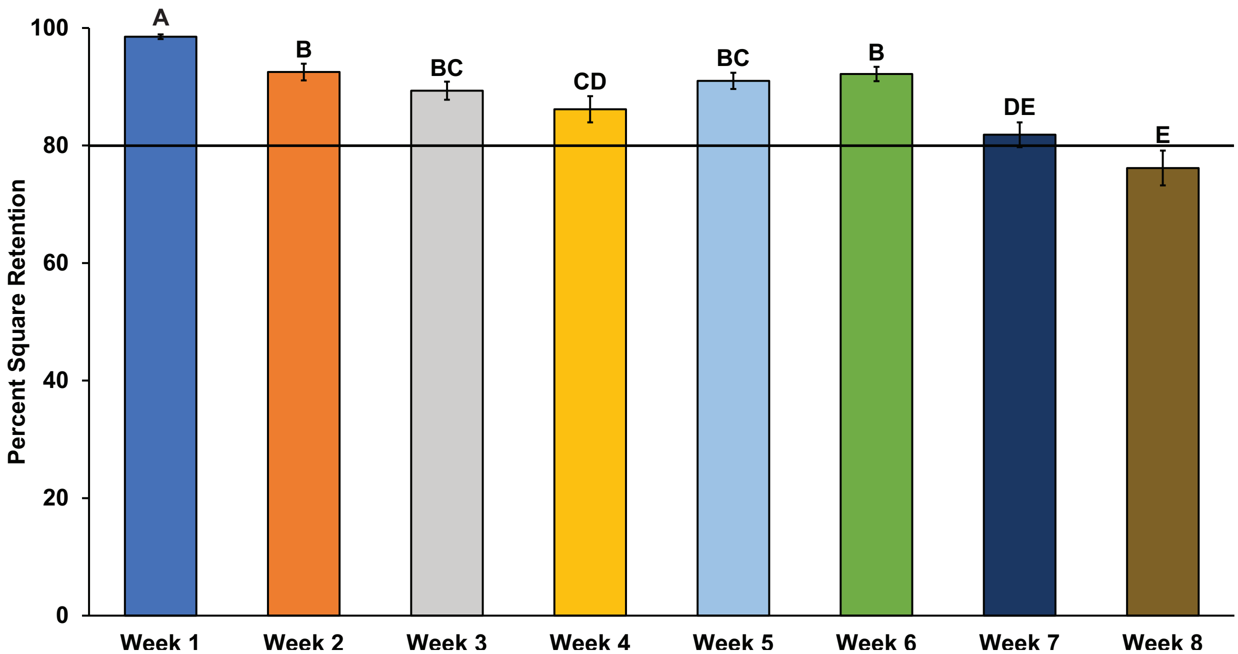

Figure 17. Percent square retention by week of sample in the ThryvOn variety at the Sidon, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 0.73; df = 5, 89.58; *p* = 0.60) (Week: F = 26.27; df = 7, 50.81; *p* < 0.01) (Week*Treatment: F = 0.93; df = 35, 72.19; *p* = 0.59). Solid black line indicates the current action threshold (80%) for reference across the figure.

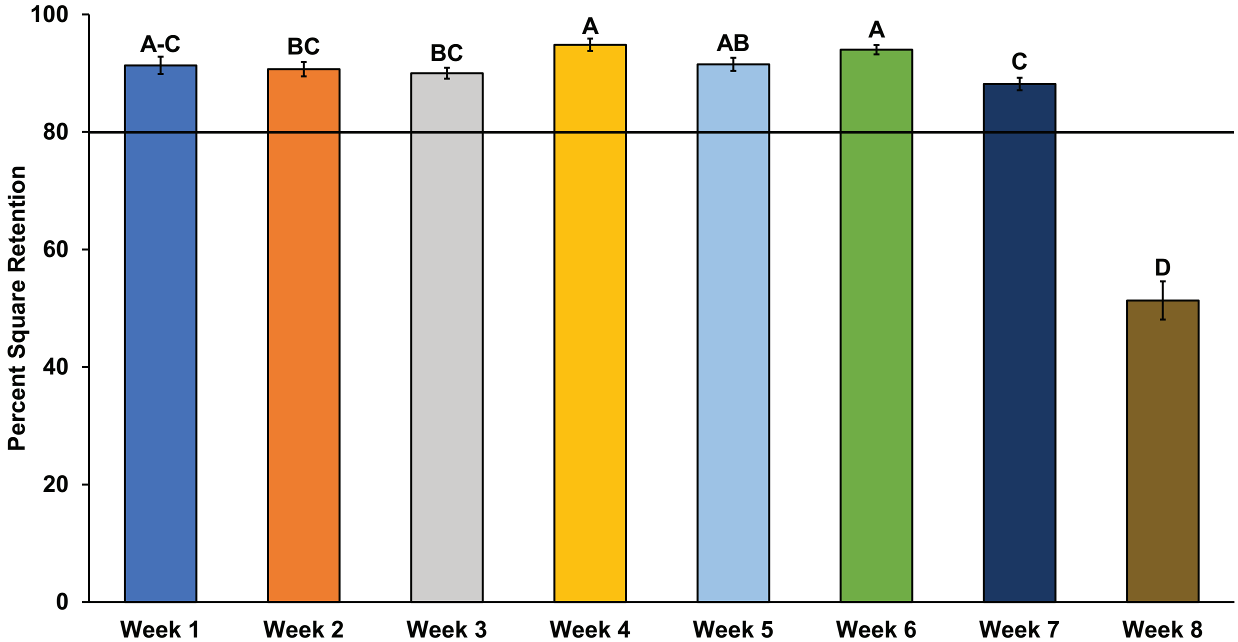

Figure 18. Percent square retention by week of sample in the ThryvOn variety at the Stoneville, MS location. Means with a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05). (Treatment: F = 0.90; df = 5, 52.16; *p* = 0.49) (Week: F = 21.94; df = 7, 56.49; *p* < 0.01) (Week*Treatment: F = 0.51; df = 35, 83.64; *p* = 0.99). Solid black line indicates the current action threshold (80%) for reference across the figure.

Table 3. Mean (SEM) treatment lint yields for both varieties across all locations

Treatment	Non-ThryvOn (DP 1646)	ThryvOn (DP 2131)
	---------- Kg ha^{-1} ----------	
UTC	416.48 (68.37) b	782.40 (48.44) b
No Exclusions	839.42 (46.64) a	932.16 (57.25) a
No Organophosphates	824.66 (31.23) a	945.32 (62.31) a
No Pyrethroids	744.09 (31.14) a	929.46 (40.42) a
No Neonicotinoids	833.84 (57.64) a	936.29 (53.97) a
No Sulfoximines	780.21 (53.41) a	895.10 (44.83) a
F	20.35	3.26
df	5, 55	5, 55
p	<0.01	0.01

Means followed by a common letter are not significantly different according to Fisher's Protected LSD (α = 0.05).

there will be long-term consequences of inevitable resistance development. Although Snodgrass et al. (2009) documented organophosphate and pyrethroid resistance in the mid-southern U.S. tarnished plant bug populations, a tank-mix combining these two classes is an integral application for both achieving adequate control and preserving cotton yields.

Additionally, insecticide-resistance modeling research has shown that mixtures are more effective at delaying resistance evolution, as mixtures generate redundant kill by exposing individuals resistant to one insecticide to another to increase mortality (Madgwick and Kanitz, 2024). Transform WG® (sulfoxaflor; the only product in the sulfoximines group) is one of the most effective insecticides currently labeled for tarnished plant bug control in the mid-southern U.S. The loss of this product would increase the need for tank-mix applications of less selective insecticides to achieve similar management results. Any loss of the insecticide options would eliminate one of the main strategies of an integrated pest management (IPM) program: rotation of insecticide classes. With current use strategies and lack of novel modes of action, rotational options are already limited, and any significant changes to current labels would further tighten those constraints.

Although these data suggest that insecticide option loss does not equal loss of yield, resistance development in the long term would result in producers having few to no affordable or efficacious options for tarnished plant bug control in cotton. Additionally, repeated runs of this experiment or multi-year effects might differ. Less effective insecticide options would force cotton producers to make more insecticide applications with increased input costs and decreased yield potentials. Development of new insecticides is an alternative option to further delay resistance. However, developing novel insecticide mode of actions is a slow, procedural process that requires tremendous monetary and time investments, efficacy and safety research, and approval from multiple governmental agencies. This process can take several years, even well over a decade, before the new pesticide reaches the commercial market for sale. From 2010 to 2014, it took approximately $286 million and 11.3 years of research to bring a new product to market (McDougall, 2016).

Although there were no significant differences between treated plots in either variety, insecticide applications were necessary for optimum yields, as all treated plots yielded significantly higher than the untreated control. Although ThryvOn cotton provides an additional Bt mode of action within the plant targeting tarnished plant bugs, this protein does not provide complete control of tarnished plant bugs. Therefore, supplemental insecticide applications will be required to maximize yield (Graham and Stewart, 2018).

Similar to findings by Corbin et al. (2020), Graham and Stewart (2018), Thrash et al. (2024), and Whitfield et al. (2023), in this study, there was a significant reduction in the number of insecticide applications for tarnished plant bugs in the ThryvOn variety, 2.07, compared to the non-ThryvOn variety, 3.07. Given ThryvOn's effects on tarnished plant bugs and the findings from these studies, cotton producers should observe a reduction in the average annual number of insecticide applications for tarnished plant bug management. This means that ThryvOn technology results in fewer trips across the field, reducing producers' input costs such as time, labor, fuel, and custom application fees, and allowing for potentially greater economic returns that were not included in the economic analysis of this study.

This reduction in insecticide applications also reduces the amount of insecticide active ingredients entering the environment, reducing potential off-target consequences. Although it was assumed that resistance levels were similar at all locations, some site-specific differences in pest pressure and insecticide efficacy might have influenced these results (e.g., at Glendora, the no pyrethroids treatment reached economic threshold fewer times than other treatments, perhaps due to the effective use of novaluron + acephate and sulfoxaflor). Furthermore, this reduction did not result in significant gains in economic returns compared to the other non-ThryvOn varieties (Table 1).

In the square retention data, the non-ThryvOn variety showed significantly higher square retention at all locations in the treated plots compared to the untreated controls. This is to be expected in a cotton variety that does not express any Bt proteins with activity against tarnished plant bugs, as there is no deterrence from feeding or suppression of populations without foliar insecticide intervention. At the Glendora location, the treated plots in the ThryvOn variety maintained significantly higher square retention compared to the untreated control. However, treatments were not significantly different in the ThryvOn variety at the Sidon and Stoneville locations. This is likely attributed to the variable pest pressure between locations. Considering that tarnished plant bug pressure was lower at the Sidon and Stoneville locations, the ThryvOn technology prevented significant square loss from tarnished plant bug feeding even without the added protection from foliar insecticides. However, the increased tarnished plant bug pressure at the Glendora location caused a significant reduction in percent square retention in the untreated control compared to the treated plots. These data suggest that ThryvOn's partial control can maintain fruit retention when tarnished plant bug pressure is moderate, but under higher pressure (Glendora), even ThryvOn cotton needed sprays to preserve yield. At the Stoneville and Sidon locations, the significant reductions in percent square retention in the final week of sampling in both varieties were likely unrelated to tarnished plant bug densities, but rather a function of cotton age, unfavorable weather conditions, or a combination of both. Additionally, this week of sample was intended to rate the performance of foliar insecticides applied in the previous week, as this drop in square retention is expected as cotton reaches maturity and begins to shed squares to preserve developing bolls.

In the percent threshold data, ThryvOn treatments tended to have less tarnished plant bugs on average than their non-ThryvOn mirror treatments, supported by findings from Corbin et al. (2020), Graham and Stewart (2018), and Whitfield et al. (2023). This is supported also by the number of insecticide applications made in each variety. Tarnished plant bug densities in the non-ThryvOn reached threshold more often than the ThryvOn variety, resulting in more insecticide applications on average.

Percentage of square retention is often used in conjunction with direct scouting methods during the growing season as a supplemental means of scouting for tarnished plant bugs. This is often the case with fields in which tarnished plant bug numbers are slightly below threshold in direct sampling methods, whereby an insecticide application might not be warranted. However, the continuous feeding from a subthreshold population for an extended time can result in significant fruit loss that can justify an insecticide application to preserve yield. ThryvOn cotton's ability to suppress tarnished plant bug populations during the season while maintaining higher fruit retention is a key contributor to the fewer insecticide applications required. Data suggest that the ThryvOn cotton technology has some adverse effects on tarnished plant bug nymph development, especially in the smaller instar stages, as well as a potential non-preference effect on feeding (Bachman et al., 2017; Graham and Stewart 2018). This partial control of tarnished plant bugs could result in a reduced reliance on foliar insecticides, preservation of currently used insecticide chemistry efficacy, and potentially allow the usage of less efficacious chemistries that might provide better control coupled with the ThryvOn Bt technology.

With new technologies being commercialized, it is expected that these technologies will come at a premium, as is seen with the increased seed costs of ThryvOn cotton varieties. However, the ThryvOn variety produced numerically higher yields on average compared to the non-ThryvOn variety. This increase in yield, coupled with the decreased number of insecticide applications, resulted in numerically higher net returns in all ThryvOn treatments compared to their non-ThryvOn mirror treatment. Additionally, the untreated control of the ThryvOn variety did not suffer significant economic losses compared to the treatments receiving insecticide intervention. However, it should not be assumed that insecticide intervention can be omitted in ThryvOn cotton. This lack of separation is more likely attributed to the overall low yields observed across all locations. Previous research has demonstrated significant decreases in lint yield in ThryvOn cotton when excluding foliar insecticide applications for the tarnished plant bug (Corbin et al., 2020; Graham and Stewart, 2018; Thrash et al., 2024). These differences in yield can be further exaggerated in an area with higher yield potential, whether from increased tarnished plant bug pressure, more favorable environmental conditions, or better management practices. Dramatic increases in yield would likely lead to increased net returns in insecticide-treated ThryvOn compared to untreated ThryvOn cotton. Furthermore, this analysis did not include all input costs associated with producing a cotton crop, therefore, these returns should not signify expected returns in a commercial scenario. The current recommendation is that supplemental insecticide applications will still be needed to maximize yield in ThryvOn cotton technology (Graham and Stewart, 2018).

Beyond the economic returns observed in this analysis, there is the potential for additional benefits to producers by growing ThryvOn cotton compared to non-ThryvOn cotton that were not included in this analysis. These potential benefits include a decreased amount of insecticide active ingredients entering the environment and causing off-target harm, reduced trips across the field, reduced application costs such as fuel and labor, and lowered equipment maintenance costs. ThryvOn cotton also is shown to provide excellent protection from thrips in seedling cotton, with some university guidelines recommending that no foliar insecticide applications be made for this pest in ThryvOn cotton (Bateman et al., 2023; Brown et al., 2023; Crow et al., 2023). A reduction in the number of insecticide applications made for thrips will further decrease the amount of insecticide applications needed in ThryvOn cotton, as well as further increase profitability. Considering no insecticide-exclusion treatment in either variety observed significantly lower economic returns than their respective treatment with all classes available, it stands to reason that in the short term, the loss of any insecticide class for tarnished plant bug control will not result in significant economic losses. However, as insecticide selections dwindle, increased selection pressure on the remaining effective chemistries is greatly increased, inevitably leading to increased resistance and subsequently more expensive tank mixtures of insecticides.

It is not sustainable to rely on the development of novel insecticide products to mitigate excessive losses from tarnished plant bugs. Both options come with significantly increased costs for the producer. The introduction of ThryvOn cotton technology is an important tool in helping to mitigate the damage potential of the tarnished plant bug; however, vacating labels or reducing allowed annual use rates of insecticides might ultimately reduce the overall benefit this technology provides. We suggest continued monitoring of resistance and IPM strategies to mitigate these risks. Furthermore, as this study was conducted within a single growing season in one region with one Bt cultivar and isolate variety, additional research under different conditions is needed to confirm these hypotheses.

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