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Evaluating Increase in Pyrethroid Potency Using an Insecticide Synergist for Alfalfa Weevil Control in Oklahoma

Abstract

Insecticides are an important component of any integrated pest management (IPM) program and, in most cases, provide a last resort for controlling damaging insect pests. The alfalfa weevil (AW) *Hypera postica* (Gyllenhal), an invasive insect, is an economically damaging pest of alfalfa in North America. Two-thirds of current labeled AW products are pyrethroids, limiting alternative MoA groups available for alfalfa weevil control in forage alfalfa systems. In addition, their extensive use has led to the emergence of wide-spread resistance to pyrethroids One option is the use of insecticide synergists such as piperonyl butoxide (PBO) to enhance effectiveness of existing products. The objective of this study was to evaluate increase in pyrethroid potency using an insecticide synergist for alfalfa weevil control in Oklahoma. A field trial was conducted in Stillwater, Oklahoma (Payne County). Six chemical insecticides were evaluated as stand-alone or PBO tank mixes, for efficacy in controlling AW larvae infesting the first crop of a 5-year stand of “DK A44-16 RR” alfalfa. In most treatments, PBO did not increase mortality compared to the stand-alone products. The highest percentage efficacy for PBO tank mixes was 77%. Findings indicate that synergists may improve pyrethroid performance and reduce resistance development, though they are not a universal solution. Effectiveness depends on type and level of resistance, insect

genetics, local conditions, product availability and cost, and level of management for this IPM tool.

Keywords: IPM, Alfalfa Weevil, MoA, Pyrethroids, Synergist

Introduction

Insecticides are an important component of any integrated pest management (IPM) program and, in most cases, provide a last resort for controlling damaging insect pests. While IPM provides useful tools for insect management, insect resistance to commonly used pyrethroids challenges even the best IPM strategies (Pedigo et al., 2021).

The alfalfa weevil (AW) *Hypera postica* (Gyllenhal), an invasive insect, is an economically damaging pest of alfalfa in North America (Pellissier et al., 2017). Larval feeding in first cuttings causes economic damage through defoliation, reduced forage yield, quality, and value (Hutchins et al.,1990).

In 2002, the annual economic loss due to insecticide resistance in the United States (US) was estimated at $1 billion (Clark and Yamaguchi, 2002). In 2018, this number increased to $10 billion (Gould and Koulikowski, 2018). In Oklahoma, although economic loss studies on resistance have not been conducted, yield losses in first cuttings could easily exceed 50% due to ongoing plant defoliation resulting from reduced chemical efficacy.

Pyrethroids (MoA Group 3) are highly potent insecticides that have been used extensively over the last three decades to control a wide range of pests. In general, they act mainly on the insect nervous system by modifying the normal operation of voltage-gated sodium channels, which results in uncontrolled discharges of action potentials that quickly induce exhaustion, paralysis, and eventual death of the affected insects (Narahashi, 1992).

Modern pyrethroids have been an economical and effective choice for controlling field crop pests, including alfalfa weevil. However, their extensive use has led to the emergence of wide-spread resistance to pyrethroids in many western alfalfa producing regions and the trend is moving eastward into states like Oklahoma. Currently, varying levels of resistance are occurring throughout Oklahoma (Seuhs, 2023). Once resistance is established in a given insect population, it becomes a serious obstacle to the continued and effective use of many pyrethroids. Thus, it is very important to formulate effective countermeasure strategies to avoid the development of pyrethroids resistance.

One of the more successful IPM approaches to delaying resistance is the use of pesticide rotations using different modes of action (IRAC, 2025). Unfortunately, two-thirds of current labeled AW products are pyrethroids, limiting alternative MoA groups available for alfalfa weevil control in forage alfalfa systems. Reliance on other products such as indoxacarb (MoA 22A) in areas where pyrethroid resistance has established (Rodbell et al., 2022), puts an increased amount of pressure on remaining products as well as increasing costs per acre.

One option is the use of insecticide synergists to enhance effectiveness of existing products.

What are synergists?

Insecticide synergists are non-pesticidal chemicals that significantly boost the effectiveness of insecticides by blocking the insect's natural metabolic enzymes, which would otherwise break down the insecticide’s active ingredient, possibly making it less effective.

Synergists are generally low in toxicity for humans. While synergists have very little impact on insects on their own, they can be tank mixed or included in the product itself. One of the more common insecticide synergists is piperonyl butoxide (PBO) (NPIC, 2025).

Insecticide synergists can be a useful tool in providing an added boost to insecticides that may have reduced efficacy on their own. Studies have shown the benefits of PBO to have synergistic activity with pyrethroids against stored product pests (Arthur et al., 2020, Quellhorst et al., 2022). Another study showed piperonyl butoxide acted as a synergist when used together with endrin and methomyl against the Egyptian cotton leafworm *Spodoptera littoralis*. The synergistic effect was higher with resistant strains than with the parental strain (El-Sayed et al., 1982).

The objective of this study was to evaluate the increase in pyrethroid potency using an insecticide synergist for alfalfa weevil control in Oklahoma.

Materials and Methods

In 2024, six chemical insecticides were evaluated in a field trial as stand-alone or PBO tank mixes, for efficacy in controlling alfalfa weevil larvae infesting the first crop of a 5-year stand of “DK A44-16 RR” alfalfa at the Agronomy Research Station in Stillwater, OK (Payne County).

Pretreatment collections indicated increasing numbers of AW larvae with a mean density of (30 larvae/30 stems). A plant height of 4.0 inches was observed with a growing degree-day accumulation of 331, prompting increased insect development, and allowing threshold to be achieved based on Oklahoma recommendations.

Insecticides were applied on 06 March using a CO^2 pressurized bicycle sprayer calibrated to deliver 20 gpa at 19 psi through 8 Teejet XR 8004 flat fan nozzles traveling at 3 mph.

Treatments were arranged in a Randomized Complete Block (RCB) design using plots 3.6 m × 7.6 m in size, replicated four times. Sampling was conducted at 7, 14, and 21 days after threshold treatment (DAT) by collecting 30 stems per plot and placing them in pre-market paper bags and transported back to the university lab. The 30 stems were then placed in standard Berlese funnels for 24 hours to extract insects for counting.

Pretreatment populations of AW were at the economic threshold (30 larvae/30 stems) at the time of application and reached a peak of (42.8 larvae/30 stems) at 14 DAT in the untreated check plots. Treatments 3, 5, 7, and 10 received Exponent (a.i., piperonyl butoxide), an insecticide synergist, to increase effectiveness of insecticide treatments.

A booster application of Steward EC (a.i., Indoxacarb) was applied to treatments 2, 3, 4, and 5 (10) days after first treatment. Treatment 8 was a split application of Steward 5.3 oz/acre, at threshold, and 6.0 oz/acre 10 days after first application. In addition, all treatments received the Organosilicone Surfactant (Dyne-amic) at 0.50% (v/v).

Dry matter yields were estimated for first harvest on 16 April by removing forage from a 3 m × 3 m area with a hand-held trimmer from each plot. Subsamples were dried for determination of moisture content and yields calculated on a dry weight/acre basis.

Percent control calculated using Abbott’s formula per treatment per sample date, then averaged across all sample dates. Abbott's formula corrects for natural insect mortality in control groups when assessing the effectiveness of a treatment. All data were analyzed using statistical software SAS 9.4 analysis of variance and differences among treatments were determined using Fisher’s Protected Least Significant Difference (LSD) ($P \leq 0.05$).

Results

Apart from treatments containing Mustang Maxx (4.0 oz/acre) + Exponent (8.0oz/acre) + Steward (8.0 oz/acre), Mustang Maxx (4.0 oz/acre) + Dimethoate (16.0 oz/acre) + Exponent (8.0 oz/acre) + Steward (8.0 oz/acre), and Warrior II (1.92 oz/acre), all other insecticide treatments or tank mixes, significantly reduced AW densities (7 DAT) below levels recovered in the untreated check plots (Table 1).

Table 1. Mean number alfalfa weevil larvae and percent efficacy.

Means within column, followed by the same letter are not significantly different. (LSD;

Treatment	Rate Oz/acre	7DAT[b]	14DAT	21DAT	Mean % Efficacy[a]	Yield[F] Lbs/acre
UTC		27.8 a	42.8 a	36.0 a		0
Mustang Maxx +Steward[ce]	4.0	15 c	31.5 b	18.8 b	40	2050 c
Mustang Maxx + EXP + Steward[cde]	4.0 + 8.0 + 8.0	22.5 ab	6.8 d	2.3 b	66	1746cd
Mustang Maxx + Dimethoate + Steward[ce]	4.0 +16.0+ 8.0	15.8 bc	15.8 cd	2.3 b	67	2543 ab
Mustang Maxx +Dimethoate +EXP + Steward[cde]	4.0 +16.0 + 8.0+ 8.0	27 a	15.8 cd	0.0 c	55	2632 a
Steward[c]	8.0	5.3 c	11.3 cd	0.0 c	85	2020c
Steward + EXP[cd]	8.0 + 8.0	2.5 d	6.8 d	15.8 b	77	1003 e
Steward + Steward[c]	5.3 +6.0	2.3 d	4.5 d	15.8 b	79	1806 d
Warrior II[c]	1.92	20.3 ab	6.8 d	4.5 b	66	856 e
Warrior II + EXP[cd]	1.92 + 8.0	16.5 bc	11.3 cd	13.5 b	60	1151 e
Lorsban[c]	24.0	7.8 cd	40.5 ab	13.5 b	48	1327 e
Lorsban + Mustang Maxx[c]	24.0 +4.0	7.5 cd	6.8 d	15.8 b	70	1526 d
Imidan[c]	1lb	19.5 b	22.5 c	40.5 a	26	2292 ab
P value		0.039	0.0073	0.1580		7.6

P= 0.05).
Treatments applied 06 Mar 2024.
[a]Mean efficacy calculated from AW sampling 7, 14, and 21 DAT. (Abbott's formula per treatment per sample date), then averaged across all dates.
[b]DAT, Days after treatment. First sample date was 7 days after treatment (13 Mar), Pretreatment sampled (06 Mar).
[c]All treatments received Organosilicone Surfactant (Dyne-amic), at 0.50 % V/V.
[d]Treatments 3, 5, 7, and 10 received pipronyl butoxide (Exponent), at 8.0 oz/A.
[e]Treatmens 2, 3, 4, 5, received a booster of Steward EC at 8.0 oz/acre 10DAT.
[f]Yield. Harvest occurred on 4/16/2024. Calculated on a dry matter basis. Zero denotes complete defoliation.

At 14 DAT, all treatments, with the exception of Lorsban 4E (24.0 oz/acre), continued to reduce AW populations when compared to untreated checks.

By the end of the sampling period (21 DAT), only plots treated with Imidan, failed to provide control that was significantly different than insect collections in untreated alfalfa.

Throughout the sampling period, only Steward EC (8.0 oz/acre) produced a mean % efficacy > 80.0. Mean percent efficacy of AW larvae from 7 DAT to 21 DAT ranged from a low of 26.0% for Imidan (1lb/acre) to a high of 85.0% for Steward EC at the 8.0 oz/acre rate.

The split application of Steward EC at (5.3 + 6.0 oz/acre) provided 79% efficacy, while Steward + Exponent (8.0 + 8.0 oz/acre) provided 77% efficacy. All other treatments were 70% or lower.

Yield at harvest ranged from a low of 0.0 for the untreated check plots to a high of 2632.0 pounds per acre for Mustang Maxx + Dimethoate + Exponent + Steward (8.0 + 16.0 + 8.0 +8.0 oz/acre).

Discussion

With alfalfa weevil resistance to currently labeled pyrethroids escalating, there are limited options available for rotation. This study evaluated the synergistic property of the insecticide synergist Exponent (a.i., piperonyl butoxide) with currently labeled products containing a.i., zeta-cypermethrin (Mustang Maxx), indoxacarb (Steward), dimethoate, lambda-cyhalothrin (Warrior II), chlorpyrifos (Lorsban), and imidan against alfalfa weevil larvae.

The rationale for combining a synergist with current labeled products relies on its action as a detoxification enzyme inhibitor, which can reduce the activity of detoxification enzymes in some insects, therefore, aiding in insecticide efficacy.

Our data indicate that tank mixes containing PBO resulted in lower mortality of alfalfa weevil larvae in two of the four treatments compared to non-tank mixed treatments.

Tank mixes of Mustang Maxx + Exponent + Steward, Mustang Maxx + Dimethoate + Exponent + Steward both showed significant decrease in efficacy when PBO was added. It was only after the booster application of Steward EC 10 days after threshold treatment (as directed by protocol) that an increase in efficacy (14-21 DAT) occurred.

The addition of PBO provided a significant increase in efficacy for the Steward + Exponent (8.0 + 8.0 oz/acre) tank mix. In comparison, a slight increase in efficacy occurred when adding PBO to the Warrior II treatment, however, the difference was not significant. It should be noted that even when an increase in efficacy occurred, no PBO tank mix, including those with the Steward booster, increased mean percent efficacy to expected levels of 85-90% (Finney, 1993).

A possible explanation is the type of synergist used, resistance, or antagonistic effects. Common examples of chemical synergists include piperonyl butoxide (PBO), diethyl maleate (DEM), verapamil (VER) for ABC transporters, and S,S,S-tributyl phosphorotrithioate (DEF) (Ulah, R., et al., 2022). However, not all synergists are meant to inhibit the enzyme system of all insects. Therefore, a given synergist may not have the same effect on every insect (Wilkinson, 1983). In addition, synergistic and antagonistic actions in combinations of many organophosphates and other insecticides to insects and mites have shown breakdown of chemicals by the insect vary based on the genetic make-up of the insect and its adaptability to break down not only chemical insecticides but also the synergist (Sun and Johnson, 1960). Another possibility is the insect's resistance to the chemical is simply too great and any effect by the synergist is negligible.

Synergists have been used commercially for about fifty years and have contributed significantly to improving the efficacy of insecticides, particularly when problems of resistance have arisen. The mode of action of many synergists is to block the metabolic systems that would otherwise break down insecticide molecules (Yadav et al., 2018).

Although previous work has demonstrated increased mortality of the red flower beetle, *T. castaneum* after the combined exposures of PBO and cypermethrin (Mukhtar et al., 2023), and PBO and esfenvalerate (Yao et al., 2019), the effects of synergists on mortality can vary. For example, the combined exposures of PBO and dichlorvos had no effect on the mortality of *T. castaneum*, while application of DEM, another common synergist, and dichlorvos resulted in significantly increased mortality (Yao et al., 2019). Also, PBO did not increase the mortality in the maize weevil *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae), but DEM and other synergists significantly increased the mortality caused by lambda-cyhalothrin (Haddi et al., 2018). Collectively, this demonstrates that the effects of these synergists can vary depending upon the type of synergists and insecticides used, insect species, and levels or duration of insecticide exposure.

Why this matters for alfalfa weevil / insecticide resistance

Resistance to certain insecticide classes (especially **pyrethroids**, e.g. lambda-cyhalothrin, zeta-cypermethrin) is documented in many western US states. LC_{50} assays and field trials show significant reductions in efficacy in weevil populations. As resistance increases, growers have fewer effective options, costs rise, and yield losses increase (Rodbell et al., 2024).

Synergists potentially offer a tool to restore or improve efficacy of insecticides that are becoming less effective due to metabolic resistance. They may also help slow the evolution of resistance by reducing the dosage or frequency of the insecticide needed, or by making other classes usable in places where resistance is establishing.

Limitations, challenges, and risks

While there is promise is utilizing synergists, there are several important drawbacks and concerns when considering insecticide synergists in alfalfa weevil control.

Synergists are only effective if the resistance is metabolic (i.e. detoxification via enzymes). Differences in insect genetics mean use of a synergist is not a one size fits all. It could mean identifying what specific synergist works on a particular pest. If resistance is due to other mechanisms—such as target-site (e.g. knockdown resistance, KDR), reduced penetration, behavioral avoidance—synergists may have little effect.

Synergists may not be registered for all crops or insects; mixing synergists with certain insecticides may not be allowed under product labels.

Synergist products may add cost (either upfront or via specialized products) for the grower; possibly that some synergists are more expensive, harder to get, or not available. Exponent, the product used in the current study used at the 8.0 oz/acre rate would add an additional cost of around $13.00/acre.

While many synergists are relatively non-toxic by themselves, some may have unintended effects (on beneficial insects, pollinators, soil organisms, etc.). Also, possibility of synergists interacting with other chemicals causing unexpected toxicity or antagonistic effects.

Repeated use of the same synergist + insecticide could select for insects that overcome the synergist (e.g., upregulated alternative detox pathways, mutations in the target enzymes) or enhance resistance to current pyrethroids.

Coverage is important; larvae must contact treated foliage; sometimes spray volumes, spray timing, growth stage of alfalfa, weather, etc. complicate getting good control. Also, synergists may need specific formulation with insecticide, or timing (pre-treatment or co-treatment) for maximum effect.

Conclusions

This study provides baseline data in Oklahoma about the effect of the insecticide synergists piperonyl butoxide (PBO) on the efficacy of currently labeled pyrethroids against alfalfa weevil larvae. When added to four treatments, PBO did not increase mortality in two of the four, compared to the stand-alone products, suggesting that potential benefits of incorporating PBO along with pyrethroids would be negligible. While increase in efficiency was observed in two PBO treatments, only one was significant 7DAT. Even with a booster application of Steward EC, efficacy in PBO treated plots did not reach expected levels for control (90%) throughout the 7-21 DAT sampling period. This may indicate extreme resistance levels to pyrethroids are occurring in these particular insect populations.

Using an insecticide synergist offers promise for improving insecticide performance against alfalfa weevil, especially in populations where resistance is just starting to build. Synergists may help increase some efficacy and slow development, but they are not a cure all or one size fits all. Effectiveness depends on the synergist, type and level of resistance, insect genetics, local conditions, product availability and cost, and level of management for this IPM tool.

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Conflict of Interest

The author declared there are no conflicts of interest.

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