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Efficacy of Pyroxasulfone Plus Encapsulated Saflufenacil Applied Postemergence Alone and With Partner Herbicides for Weed Control in Corn

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Abstract

A newly developed formulation of pyroxasulfone and saflufenacil features encapsulated saflufenacil, enhancing corn safety and extending the application window from preemergence (PRE) to early postemergence (ePOST). Pyroxasulfone plus encapsulated saflufenacil applied ePOST alone and in herbicide mixtures were examined for weed control efficacy and corn tolerance. It was hypothesized that the application of pyroxasulfone plus encapsulated saflufenacil with an additional herbicide would improve weed control efficacy. Six field experiments were completed at three locations, in southwestern Ontario in 2022 and 2023. All herbicide treatments were applied at V1 corn (3-leaf stage). Pyroxasulfone plus encapsulated saflufenacil was applied alone, at 146 or 245 g ai ha^{-1}, and with the following herbicide partners: dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine. Weed control, density, and biomass and corn injury and yield were assessed. All pyroxasulfone plus encapsulated saflufenacil herbicide mixtures caused 1 to 4, 0 to 1, and 0% corn injury at 1, 2, and 4 weeks after application (WAA), respectively. The addition of a herbicide partner to pyroxasulfone plus encapsulated saflufenacil (146 or 245 g ai ha^{-1}) improved common lambsquarters (*Chenopodium album* L.) control at 4 and 8 WAA; in contrast, there was no improvement in redroot pigweed (*Amaranthus retroflexus* L.) or foxtail species (*Setaria* spp.) control. All pyroxasulfone plus encapsulated saflufenacil herbicide mixtures provided similar control of common lambsquarters, redroot pigweed, and foxtail species with the industry standard, *S*-metolachlor/atrazine/mesotrione/bicyclopyrone. Corn yield for all herbicide treatments evaluated was similar to the weed-free control.

Keywords: biomass, corn injury, corn yield, density, encapsulation, herbicide formulation, herbicide mixture, weed control

1. Introduction

Herbicides are the most commonly used method for weed control in field corn with 96% of hectares receiving at least one herbicide application in the USA (NASS, 2022). Without the use of any weed management tactics, corn yield loss in North America is estimated to be 50% (Soltani et al., 2016). Pyroxasulfone plus encapsulated saflufenacil is another potential herbicide option for weed control in corn. Pyroxasulfone is a Group 15 very long-chain fatty acid elongases (VLCFAE) inhibitor and saflufenacil is a Group 14 protoporphyrinogen oxidase (PPO) inhibitor (Shaner, 2014). Previous research on saflufenacil has concluded that crop injury is unacceptable when applied postemergence (POST) (Soltani et al., 2009), but the encapsulation of saflufenacil may allow for a wider application period that extends to V1 (3-leaf stage) corn. Encapsulation involves coating the active ingredient which restricts herbicidal activity until the herbicide coating is broken down (Anonymous, 2021; Armel et al., 2003). This has also been achieved with the active ingredient, acetochlor (Group 15, Warrant®) to expand the application window in soybean (Anonymous, 2021; Armel et al., 2003).

The application of a Group 14 with a Group 15 herbicide can provide improved control of weeds such as green foxtail (*Setaria viridis* (L.) P. Beauv.), common lambsquarters (*Chenopodium album* L.), and common ragweed (*Ambrosia artemisiifolia* L.) (Belfry et al., 2015); the interaction, established by Tidemann et al. (2014), is additive. Pyroxasulfone provides control of small-seeded annual grasses and some small-seed annual broadleaf weeds including barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), green foxtail, yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.), giant foxtail (*Setaria faberi* Herrm.), Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot), waterhemp (*Amaranthus tuberculatus* (Moq.) J. D. Sauer), Palmer amaranth (*Amaranthus palmeri* S. Watson), and redroot pigweed (*Amaranthus retroflexus* L.) (Anonymous, 2022; Yamaji et al., 2014) while saflufenacil, a broadleaf herbicide, controls common lambsquarters, redroot pigweed, common ragweed, wild buckwheat (*Fallopia convolvulus* L.), wild mustard (*Sinapis arvensis* L.), and velvetleaf (*Abutilon theophrasti* Medik.). By combining pyroxasulfone and saflufenacil there is potential for a broad spectrum of small-seeded annual grasses and broadleaf weed control.

In addition to broadening the spectrum of weed species controlled, there are many other benefits from herbicide mixtures such as reducing the number of herbicide applications, the potential for synergism, and a strategy to delay the evolution of herbicide resistance if different modes of action (MOA) are included (Beckie and Reboud, 2009). For this study, each herbicide partner was chosen because they are commonly used, could fill a gap in the spectrum of weeds controlled, and/or offer different effective MOAs. The herbicide mixtures evaluated in this study were dicamba/diflufenzopyr (Groups 4/19), mesotrione + atrazine (Group 27 + 5), and topramezone/dimethenamid-p + atrazine (Group 27/15 + 5); dicamba/diflufenzopyr included the safener isoxadifen. Dicamba/diflufenzopyr controls wild buckwheat, corn spurry (*Spergula arvensis* L.), Canada fleabane (*Erigeron canadensis* (L.) Cronq.), common lambsquarters, ladysthumb (*Persicaria maculosa* Gray), nightshade spp. (*Solanum* spp.), pigweed spp., ragweed spp., and velvetleaf (OMAFRA, 2021). Mesotrione + atrazine controls Canada fleabane, common lambsquarters, mustard spp., nightshade spp., pigweed spp., velvetleaf, waterhemp, and ladysthumb. Toprampazone/dimethenamid-p + atrazine controls barnyardgrass, large crabgrass, smooth crabgrass (*Digitaria ischaemum* Schreb.), witchgrass (*Panicum capillare* L.), wild buckwheat, corn spurry, ladysthumb, common lambsquarters, mustard spp., nightshade spp., pigweed spp., and common ragweed (OMAFRA, 2021).

This is a new formulation of existing active ingredients, pyroxasulfone and saflufenacil, and there is limited research on its weed control efficacy applied alone and/or with a herbicide partner. The objective of this study was to determine the effect of the pyroxasulfone plus encapsulated saflufenacil on weed control efficacy, corn injury and yield.

2. Materials and Methods

This study consisted of six trials completed in the 2022/23 field seasons conducted at three locations, two sites at the University of Guelph Ridgetown Campus, Ridgetown, Ontario, Canada and one site at the BASF Research Farm located near Belmont, Ontario, Canada (Table 1). Trials were set up as RCBD with four replications of 14 treatments applied to 2 × 8 m plots. Prior to planting, all three sites were chisel ploughed the previous fall and S-tine cultivated in the spring. Fertilizer was applied based on soil test results and OMAFRA nutrient recommendations. Corn was planted in rows spaced 75 cm apart at a rate of approximately 80,000 seeds ha^{-1} to a depth of 5 cm. Refer to Table 1 for more soil and crop information. Herbicide treatments were applied POST (V1; 3-leaf stage) using a CO_2-pressurized backpack sprayer that was calibrated to deliver 200 L ha^{-1} at 240 kPa. The pyroxasulfone plus encapsulated saflufenacil was applied alone at 146 or 245 g ai ha^{-1} and in combination with dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine. All herbicide treatments included glyphosate at 900 g ai ha^{-1}.

Table 1. Year, location, soil characteristics, corn hybrid, planting, emergence, and harvest dates, and herbicide application date for six trials conducted in Ontario, Canada in 2022 and 2023

Year	Location	Soil characteristics				Crop information				Herbicide application date
		Texture	OM	pH	CEC	Hybrid	Planting date	Emergence date	Harvest date	
			--------- % --------							
2022	Ridgetown Campus (A)	Sandy loam	2.9	7.4	8.4	DKC39-97RIB	May 11	May 17	Nov 4	May 24
	Ridgetown Campus (B)	Clay loam	4.1	7.2	18.0	DKC39-97RIB	May 13	May 23	Nov 2	Jun 1
	BASF Research Farm	Loam	2.9	6.6	13.5	DKC48-56RIB	Jun 14	Jun 21	Nov 10	Jun 27
2023	Ridgetown Campus (A)	Sandy clay loam	4.3	6.6	10.8	DKC39-97RIB	May 11	May 19	Oct 24	May 26
	Ridgetown Campus (B)	Clay loam	4.9	6.7	15.2	DKC39-97RIB	May 16	May 25	Oct 25	Jun 2
	BASF Research Farm	Loam	2.8	7.2	9.6	DKC48-56RIB	May 25	Jun 2	Nov 15	Jun 9

Note. Abbreviations: OM, organic matter; CEC, cation exchange capacity.

Assessments included visible corn injury, visible weed control, weed density, weed biomass, and corn yield. Visible corn injury was rated 1, 2, and 4 weeks after application (WAA), visible weed control at 4 and 8 WAA, and density and biomass at 8 WAA. Visible corn injury and weed control were based on a 0 to 100 scale, where 0 is no visible symptoms and 100 is complete plant death. Weed density and biomass were determined by placing a 0.25 m^2 quadrat at two random locations within each plot, counting the number of each weed species within each quadrat, and placing aboveground plant biomass in separate bags by species. The weed biomass was dried and then weighed. Weed evaluations were completed on natural populations that included common lambsquarters, redroot pigweed, and foxtail species. Corn was combined at harvest maturity; moisture content and weight were recorded. Corn yield was adjusted to 15.5% moisture prior to analysis.

Statistical analysis was completed using GLIMMIX, a mixed model analysis of variance, in SAS 9.4 (SAS Institute Inc., Cary, NC). Data from all site-years were combined and analyzed together to allow for interpretation across multiple environments. Fixed effect was herbicide treatment and random effects were environment, replications in each environment, and herbicide treatments in different environments. Prior to analysis one pigweed species environment and two foxtail species environments were removed due to low weed density. Distribution plot, residual plots, and Shapiro-Wilk were used to analyze normality and determine which transformations were best-suited to improve the fit of the data to a normal distribution. An arcsine transformation was used for visible corn injury and weed control, lognormal for density and biomass data; yield data was normally distributed and was not transformed. Least Square Means and Tukey-Kramer test were used to establish significance and treatment differences with a p-value of 0.05. All transformed data were back transformed for the purpose of presentation.

3. Results and Discussion

3.1 Injury

Corn injury following POST applications of pyroxasulfone plus encapsulated saflufenacil was less than 5% in all treatments (Table 2); injury symptoms included water-soaked lesions and speckled chlorosis. At 1 and 2 WAA, dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine, applied alone caused no corn injury. At 1 and 2 WAA, all pyroxasulfone plus encapsulated saflufenacil treatments caused 0 to 4% and 0 to 1% corn injury, respectively; there were no differences among treatments at 2 WAA. Corn injury was transient with no injury at 4 WAA (data not shown). The level of corn injury caused by the encapsulated formulation of saflufenacil plus pyroxasulfone in this study is agronomically acceptable. The authors suggest that the corn injury was caused by the encapsulated saflufenacil because field corn has excellent tolerance to both PRE and ePOST applications of pyroxasulfone (Nakatani et al., 2016; Shaner, 2014). In contrast, saflufenacil (suspension formulation) caused up to 25% corn injury when applied POST at 2 to 3 leaf stage, without an adjuvant (Soltani et al., 2009).

Table 2. Influence of pyroxasulfone plus encapsulated saflufenacil herbicide mixtures on corn injury 1 and 2 weeks after application and corn yield from six trials conducted in Ontario, Canada in 2022 and 2023

Herbicide treatment[a]	Rate	Corn Injury[c]		Yield
		1 WAA[b]	2 WAA	
	g ai ha^{-1}	------------- % -------------		T ha^{-1}
Untreated control		0 a	0 a	6.4 b
Weed-free control		0 a	0 a	11.8 a
Pyroxasulfone/saflufenacil	146	2 b	0 a	10.9 a
Pyroxasulfone/saflufenacil	245	4 b	1 a	11.2 a
Dicamba/diflufenzopyr[d]	200	0 a	0 a	11.3 a
Mesotrione + atrazine	100 + 500	0 a	0 a	11.4 a
Topramezone/dimethenamid-p + atrazine	642.5 + 500	0 a	0 a	11.3 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	146 + 200	1 b	0 a	11.3 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	245 + 200	3 b	0 a	11.3 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	146 + 100 + 500	2 b	0 a	11.3 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	245 + 100 + 500	4 b	0 a	11.6 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	146 + 642.5 + 500	3 b	1 a	11.3 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	245 + 642.5 + 500	4 b	1 a	11.5 a
S-metolachlor/atrazine/mesotrione/bicyclopyrone[e]	2026	0 a	0 a	11.7 a

Note. Abbreviations: WAA, weeks after application.

[a] Glyphosate at 900 g ai ha^{-1} was added to all herbicide treatments.

[b] Means followed by the same letter are not significantly different according to the Tukey-Kramer multiple range test ($P < 0.05$).

[c] Corn injury data presented was backtransformed from arcsine transformation.

[d] Dicamba/diflufenzopyr includes the safener isoxadifen.

[e] *S*-metolachlor/atrazine/mesotrione/bicyclopyrone includes the safener benoxacor.

3.2 Common Lambsquarters Control

Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} controlled common lambsquarters 87 and 90%, respectively at 4 WAA (Table 3). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine controlled common lambsquarters 83, 98, and 95%, respectively. The addition of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil improved common lambsquarters control. Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} controlled common lambsquarters 82 and 88%, respectively at 8 WAA (Table 3). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine controlled common lambsquarters 77, 95, and 91%, respectively. When compared to pyroxasulfone plus encapsulated saflufenacil applied alone the addition of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil improved common lambsquarters control with one exception; the addition of topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil at 245 g ai ha^{-1} did not improve common lambsquarters control. Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} reduced common lambsquarters density 59 and 88%, respectively (Table 3). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine reduced common lambsquarters density 18, 97, and 94%, respectively. The addition of mesotrione + atrazine or topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil at 146 g ai ha^{-1} decreased common lambsquarters density when compared to the pyroxasulfone plus encapsulated saflufenacil applied alone. In contrast, there was no decrease in density with the addition of dicamba/diflufenzopyr. The application of pyroxasulfone plus encapsulated saflufenacil at 245 g ai ha^{-1} with dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine did not reduce common lambsquarters density when compared to pyroxasulfone plus encapsulated saflufenacil applied alone. Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} reduced common lambsquarters biomass 81 and 93%, respectively (Table 3). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine reduced common lambsquarters biomass 92, 97, and 96%, respectively. When compared to pyroxasulfone plus encapsulated saflufenacil applied alone the addition of mesotrione + atrazine to pyroxasulfone plus encapsulated saflufenacil at 146 g ai ha^{-1} decreased common lambsquarters biomass; there was no decrease in common lambsquarters biomass with the addition of dicamba/diflufenzopyr or topramezone/dimethenamid-p to pyroxasulfone plus encapsulated saflufenacil. The herbicide mixture of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine with pyroxasulfone plus encapsulated saflufenacil at 245 g ai ha^{-1} did not reduce common lambsquarters density when compared to pyroxasulfone plus encapsulated saflufenacil applied alone. The industry standard, *S*-metolachlor/atrazine/mesotrione/bicyclopyrone controlled common lambsquarters 99 and 98% at 4 and 8 WAA, respectively and reduced density and biomass 100%. All pyroxasulfone plus encapsulated saflufenacil herbicide mixtures provided ≥ 95% common lambsquarters control and reduced density and biomass ≥ 94 and 97%, respectively; the level of control and density and biomass reductions were similar to *S*-metolachlor/atrazine/mesotrione/bicyclopyrone.

Common lambsquarters control with pyroxasulfone plus encapsulated saflufenacil in this study ranged from 82 to 90% (Table 3). Mahoney et al. (2014) and Belfry et al. (2015) recorded similar common lambsquarters control with group 15/14 herbicide mixtures of pyroxasulfone/flumioxazin (83 to 99%) and pyroxasulfone + sulfentrazone (83 to 95%) applied PRE, respectively. Previous research on the suspension formulation of saflufenacil reported > 80% control of many broadleaf weed species including common lambsquarters (Creech et al., 2016; OMAFRA, 2021; Shaner, 2014) and although pyroxasulfone has activity on some small-seeded broadleaf weeds, it does not provide high control of common lambsquarters (Nakatani et al., 2016). Nakatani et al. (2016) reported that pyroxasulfone applied PRE only reduces common lambsquarters competition.

Table 3. Influence of pyroxasulfone plus encapsulated saflufenacil herbicide mixtures on common lambsquarters control (4 and 8 weeks after application), density, and biomass in corn from six trials conducted in Ontario, Canada in 2022 and 2023

Herbicide treatment[a]	Rate	Control[c]		Density	Biomass
		4 WAA[b]	8 WAA		
	g ai ha^{-1}	---------- % ---------		No. plants m^{-2}	g m^{-2}
Untreated control		0	0	34 d	66.1 d
Weed-free control		100	100	0 a	0.0 a
Pyroxasulfone/saflufenacil	146	87 bc	82 de	14 bc	12.3 c
Pyroxasulfone/saflufenacil	245	90 bc	88 cde	4 ab	4.9 bc
Dicamba/diflufenzopyr[d]	200	83 c	77 e	28 cd	5.3 bc
Mesotrione + atrazine	100 + 500	98 a	95 abc	1 a	1.7 ab
Topramezone/dimethenamid-p + atrazine	642.5 + 500	95 ab	91 bcd	2 ab	2.6 abc
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	146 + 200	97 a	96 abc	2 ab	2.0 abc
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	245 + 200	98 a	97 ab	1 a	1.7 abc
Pyroxasulfone/saflufenacil + mesotrione + atrazine	146 + 100 + 500	99 a	98 a	1 a	1.7 ab
Pyroxasulfone/saflufenacil + mesotrione + atrazine	245 + 100 + 500	99 a	97 ab	1 a	0.9 ab
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	146 + 642.5 + 500	99 a	97 ab	1 a	2.3 abc
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	245 + 642.5 + 500	98 a	95 abc	2 ab	1.9 abc
S-metolachlor/atrazine/mesotrione/bicyclopyrone[e]	2026	99 a	98 a	0 a	0.3 a

Note. Abbreviations: WAA, weeks after application.

[a] Glyphosate at 900 g ai ha^{-1} was added to all herbicide treatments.

[b] Means followed by the same letter are not significantly different according to the Tukey-Kramer multiple range test ($P < 0.05$).

[c] Control data presented was backtransformed from arcsine transformation; density and biomass data presented was backtransformed from log transformation.

[d] Dicamba/diflufenzopyr includes the safener isoxadifen.

[e] *S*-metolachlor/atrazine/mesotrione/bicyclopyrone includes the safener benoxacor.

3.3 Redroot Pigweed Control

Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} controlled redroot pigweed 95 and 98% at 4 WAA and 92 and 96% at 8 WAA, respectively (Table 4). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine controlled redroot pigweed 86, 97, and 98% at 4 WAA and 85, 95, and 96% at 8 WAA, respectively. Pyroxasulfone plus encapsulated saflufenacil with tank-mix partners controlled redroot pigweed 99% and 97 to 98% at 4 and 8 WAA, respectively. When compared to pyroxasulfone plus encapsulated saflufenacil applied alone there was no improvement in redroot pigweed control from the addition of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil. Pyroxasulfone plus encapsulated saflufenacil (146 and 245 g ai ha^{-1}) reduced pigweed density and biomass 94 and 97%, respectively. Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine reduced redroot pigweed density 50, 94, and 94% and biomass 96, 97, and 98%, respectively. When compared to pyroxasulfone plus encapsulated saflufenacil applied alone there was no decrease in redroot pigweed density or biomass from the co-application of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine with pyroxasulfone plus encapsulated saflufenacil. Pyroxasulfone plus encapsulated saflufenacil applied alone (146 or 245 g ai ha^{-1}) or with a herbicide partner provided similar redroot pigweed control, density, and biomass as the industry standard, *S*-metolachlor/atrazine/mesotrione/bicyclopyrone.

Table 4. Influence of pyroxasulfone plus encapsulated saflufenacil herbicide mixtures on redroot pigweed control (4 and 8 weeks after application), density, and biomass in corn from six trials conducted in Ontario, Canada in 2022 and 2023

Herbicide treatment[a]	Rate	Control[c]		Density	Biomass
		4 WAA[b]	8 WAA		
	g ai ha^{-1}	---------- % ---------		No. plants m^{-2}	g m^{-2}
Untreated control		0	0	18 c	96.7 b
Weed-free control		100	100	0 a	0.0 a
Pyroxasulfone/saflufenacil	146	95 ab	92 ab	1 ab	3.0 a
Pyroxasulfone/saflufenacil	245	98 a	96 a	1 ab	2.5 a
Dicamba/diflufenzopyr[d]	200	86 b	85 b	9 b	3.8 a
Mesotrione + atrazine	100 + 500	97 a	95 a	1 ab	3.2 a
Topramezone/dimethenamid-p + atrazine	642.5 + 500	98 a	96 a	1 ab	1.5 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	146 + 200	99 a	97 a	1 a	1.1 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	245 + 200	99 a	98 a	0 a	1.0 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	146 + 100 + 500	99 a	98 a	0 a	1.3 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	245 + 100 + 500	99 a	98 a	0 a	0.8 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	146 + 642.5 + 500	99 a	98 a	0 a	0.9 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	245 + 642.5 + 500	99 a	98 a	0 a	0.2 a
S-metolachlor/atrazine/mesotrione/bicyclopyrone[e]	2026	99 a	98 a	0 a	0.9 a

Note. Abbreviations: WAA, weeks after application.

[a] Glyphosate at 900 g ai ha^{-1} was added to all herbicide treatments.

[b] Means followed by the same letter are not significantly different according to the Tukey-Kramer multiple range test ($P < 0.05$).

[c] Control data presented was backtransformed from arcsine transformation; density and biomass data presented was backtransformed from log transformation.

[d] Dicamba/diflufenzopyr includes the safener isoxadifen.

[e] *S*-metolachlor/atrazine/mesotrione/bicyclopyrone includes the safener benoxacor.

The high levels of redroot pigweed control with pyroxasulfone plus encapsulated saflufenacil are corroborated by previous studies on pyroxasulfone and saflufenacil applied alone. Geier et al. (2009) showed that saflufenacil controls many pigweed species (> 90% biomass reduction), including redroot pigweed, at rates ≥ 9 g ai ha^{-1} while Yamaji et al. (2014) showed that pyroxasulfone a rate ≥ 16 g ai ha^{-1} was required for redroot pigweed control. Another herbicide mixture, pyroxasulfone/flumioxazin (Group 15/14), applied PRE at 80 to 480 g ai ha^{-1} provided 100% control of pigweed species (Mahoney et al., 2014).

3.4 Foxtail Species Control

Pyroxasulfone plus encapsulated saflufenacil applied at 146 or 245 g ai ha^{-1} controlled foxtail species 93 and 98% at 4 WAA and 87 and 92% at 8 WAA, respectively (Table 5). Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine controlled foxtail 87, 52, and 98% at 4 WAA and 82, 52, and 92% at 8 WAA, respectively. Pyroxasulfone plus encapsulated saflufenacil applied at 146 and 245 g ai ha^{-1} reduced pigweed density 68 to 71% and biomass 96 to 98%, respectively. Dicamba/diflufenzopyr, mesotrione + atrazine, and topramezone/dimethenamid-p + atrazine reduced foxtail species density 68, 16, and 81% and biomass 98, 92, and 99%, respectively. When compared to pyroxasulfone plus encapsulated saflufenacil applied alone the addition of dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine to pyroxasulfone plus encapsulated saflufenacil (146 or 245 g ai ha^{-1}) did not improve foxtail species control, or reduce foxtail species density and biomass (Table 5). Pyroxasulfone plus encapsulated saflufenacil applied alone (146 or 245 g ai ha^{-1}) or with a herbicide partner provided similar foxtail species control, and density and biomass reduction as the industry standard, *S*-metolachlor/atrazine/mesotrione/bicyclopyrone.

Pyroxasulfone provided excellent foxtail species control with ≥ 98% control 4 WAA when applied at a rate of 32 g ai ha^{-1} (Yamaji et al., 2014). Whereas previous research on the suspension concentrate formulation of saflufenacil has limited activity on grass weed species (Jhala et al., 2013). In this study pyroxasulfone plus encapsulated saflufenacil applied at 245 g ai ha^{-1} controlled foxtail species 98% (Table 5). Mahoney et al. (2014) reported similar results with 98% green foxtail control when pyroxasulfone/flumioxazin (Group 15/14) was applied PRE at 240 g ai ha^{-1}.

Table 5. Influence of pyroxasulfone plus encapsulated saflufenacil herbicide mixtures on foxtail species control (4 and 8 weeks after application), density, and biomass in corn from six trials conducted in Ontario, Canada in 2022 and 2023

Herbicide treatment[a]	Rate	Control[c]		Density	Biomass
		4 WAA[b]	8 WAA		
	g ai ha^{-1}	---------- % ----------		No. plants m^{-2}	g m^{-2}
Untreated control		0	0	31 c	44.5 b
Weed-free control		100	100	0 a	0.0 a
Pyroxasulfone/saflufenacil	146	93 a	87 ab	10 ab	1.6 a
Pyroxasulfone/saflufenacil	245	98 a	92 ab	9 abc	0.9 a
Dicamba/diflufenzopyr[d]	200	87 ab	82 b	10 abc	0.8 a
Mesotrione + atrazine	100 + 500	52 b	52 c	26 bc	3.6 a
Topramezone/dimethenamid-p + atrazine	642.5 + 500	98 a	92 ab	6 ab	0.5 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	146 + 200	97 a	92 ab	4 ab	0.6 a
Pyroxasulfone/saflufenacil + dicamba/diflufenzopyr	245 + 200	99 a	95 ab	4 ab	0.7 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	146 + 100 + 500	95 a	88 ab	14 ab	1.4 a
Pyroxasulfone/saflufenacil + mesotrione + atrazine	245 + 100 + 500	98 a	93 ab	7 ab	0.6 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	146 + 642.5 + 500	99 a	96 a	4 ab	0.3 a
Pyroxasulfone/saflufenacil + topramezone/dimethenamid-p + atrazine	245 + 642.5 + 500	99 a	95 ab	2 a	0.2 a
S-metolachlor/atrazine/mesotrione/bicyclopyrone[e]	2026	98 a	92 ab	7 ab	1.1 a

Note. Abbreviations: WAA, weeks after application.

[a] Glyphosate at 900 g ai ha^{-1} was added to all herbicide treatments.

[b] Means followed by the same letter are not significantly different according to the Tukey-Kramer multiple range test ($P < 0.05$).

[c] Control data presented was backtransformed from arcsine transformation; density and biomass data presented was backtransformed from log transformation.

[d] Dicamba/diflufenzopyr includes the safener isoxadifen.

[e] *S*-metolachlor/atrazine/mesotrione/bicyclopyrone includes the safener benoxacor.

3.5 Corn Yield

Weed interference reduced corn yield 46% in this study (Table 2). Corn yield ranged from 10.9 to 11.6 T ha^{-1} across all treatments that included pyroxasulfone/saflufenacil, which was similar to the weed-free control and industry standard (Table 2). Soltani et al. (2009) observed much higher levels of injury following POST applications of the suspension concentrate formulation of saflufenacil with an adjuvant to corn at the 3-leaf stage, which resulted in unacceptable yield loss. However, in this study, the pyroxasulfone plus encapsulated saflufenacil applied POST caused no decrease in corn yield.

4. Conclusions

Cop injury was ≤ 4% at both evaluation timings and reduced weed interference with all herbicide treatments resulted in corn yields that were similar to the industry standard and weed-free control. Pyroxasulfone plus encapsulated saflufenacil applied at the 146 g ai ha^{-1} with the herbicide partners evaluated increased control of common lambsquarters; however, redroot pigweed and foxtail species control were not improved. In this study pyroxasulfone plus encapsulated saflufenacil applied with dicamba/diflufenzopyr, mesotrione + atrazine, or topramezone/dimethenamid-p + atrazine provided similar control of common lambsquarters, redroot pigweed, and foxtail species as the industry standard. Based on the results of this study, a herbicide partner is beneficial with the application of pyroxasulfone plus encapsulated saflufenacil to achieve an elevated level of control across a broader spectrum of weed species.

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A co-author of this manuscript, Chris Budd is the Senior Biologist with BASF Canada Inc. Other authors have no conflict of interest to declare.

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