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Tolerance of White Bean to Tiafenacil Herbicide Mixtures and Control of Multiple Herbicide-Resistant Horseweed With Tiafenacil Herbicide Mixtures

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Abstract

There is limited information on the tolerance of white bean to tiafenacil herbicide mixtures applied preplant (PP) and the efficacy of tiafenacil herbicide mixtures applied PP to control multiple herbicide-resistant (MHR) horseweed. The objective aim of this research was to ascertain the tolerance of white beans to tiafenacil herbicide mixtures and determine if MHR horseweed control with tiafenacil can be improved by adding herbicide partners in a surrogate soybean crop. During 2021 and 2022 four experiments were performed to determine the tolerance of white bean to tiafenacil herbicide mixtures and five experiments were conducted to determine MHR horseweed control with tiafenacil mixtures in ON, Canada. All tiafenacil mixtures evaluated except those that included 2,4-D ester caused minimal (≤ 4%) white bean injury and had no adverse effect on white bean stand, dry biomass, height, maturity (as measured by seed moisture (SM) content at harvest), or yield. Glyphosate + tiafenacil + 2,4-D ester and glyphosate + tiafenacil + bromoxynil + 2,4-D ester caused up to 8% white bean injury but had no adverse effect on white bean stand, dry biomass, height, maturity, or yield. Glyphosate + tiafenacil or co-applied with bromoxynil, metribuzin, or 2,4-D controlled MHR horseweed 23-75%, reduced density up to 62% and reduced biomass up to 56%; consequently, horseweed interference with these tiafenacil mixtures resulted in soybean yield comparable to the non-treated (weedy) control. Glyphosate + tiafenacil + halauxifen-methyl and the co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D ester controlled MHR horseweed 73-94%, reduced density up to 79%, and reduced biomass up to 86%. Reduced MHR horseweed interference with the aforementioned tiafenacil mixtures resulted in soybean yield comparable to the weed-free control. In conclusion, all tiafenacil mixtures evaluated except those that contained 2,4-D ester can be safely used in white bean. Glyphosate + tiafenacil + halauxifen-methyl and the co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D ester provided the most consistent control of MHR horseweed.

Keywords: dry biomass, efficacy, density, herbicide resistance, seed moisture content, yield

1. Introduction

Dry bean is an important legume crop commonly grown in rotation with corn, soybean, and winter wheat by Ontario farmers to increase crop diversity, enhance soil health, break crop pest cycles, and increase net farm profitability (Janovicek et al., 2021). Dry bean contributes substantially to the economy of Ontario. On an annual basis, dry bean growers seed approximately 48,000 ha and produce nearly $100 million of dry bean each year (Bedford, 2021; OMAFRA, 2021; Soltani et al., 2022). Nearly half of the dry bean produced in Ontario are the white (navy) bean market class (Hensall Co-op, 2020).

Weeds are a primary concern in dry bean production; a meta-analysis conducted by the yield loss committee of the Weed Science Society of America (WSSA) showed that dry bean producers in North America would lose approximately 71% of their production if weeds are left uncontrolled (Soltani et al., 2018). Dry bean is sensitive to herbicides and therefore exhibit substantially greater injury than crops such as corn, soybean, or winter wheat when treated with herbicides. More research is needed to find new efficacious herbicide options that can be safely used in dry bean production and control emerging herbicide-resistant (HR) biotypes.

Tiafenacil ($C_{19}H_{18}ClF_4N_3O_5S$) is a recently introduced herbicide from the pyrimidinedione chemical family, WSSA Herbicide Group 14, that can be used to control monocot and dicot weed species applied preplant (PP) or pre-emergence (PRE) in many crops including corn, soybean, and wheat (Park et al., 2018; Anonymous, 2020). It inhibits the protoporphyrinogen IX oxidase (PPO) enzyme ultimately resulting in cell membrane peroxidation in sensitive weed species such as *Amaranthus* species, velvetleaf, common purslane, and barnyardgrass (Park et al., 2018; Haring & Hanson, 2020). Additionally, tiafenacil has been reported to suppress or control sensitive HR weed biotypes including glyphosate-resistant (GR) and multiple herbicide-resistant (MHR) weeds such as waterhemp, palmer amaranth, and horseweed (EPA, 2020; Haring & Hanson, 2020). Tiafenacil is applied at relatively low doses and degrades quickly in the soil with little risk to other organisms in the environment (EPA, 2020).

Earlier research has shown that tiafenacil (25 g a.i. per ha^{-1}) applied PRE causes minimal (0-4%) injury in azuki, kidney, small red, and white bean and caused no adverse effect on plant stand, dry biomass, height, maturity (as measured by SM content), and yield (Soltani et al., 2021b). Sprague et al. (2020) reported that tiafenacil (24 g a.i. per ha^{-1}) applied PP caused no visible black bean injury and no reduction in stand or yield. Control of weeds, especially MHR horseweed has not been consistent with the co-application of glyphosate ($C_3H_8NO_5P$) + tiafenacil (Soltani et al., 2021b; Westerveld, 2021; Westerveld et al., 2021). Earlier studies have shown that glyphosate + tiafenacil applied PP provides only 51-68% control of MHR horseweed in soybean (Soltani et al., 2021b). The co-application of glyphosate + tiafenacil with bromoxynil ($C_7H_3Br_2NO$), metribuzin ($C_8H_{14}N_4OS$), halauxifen-methyl ($C_{14}H_{11}C_{l2}FN_2O_3$), 2,4-D ester, bromoxynil + metribuzin, bromoxynil + halauxifen-methyl, or bromoxynil + 2,4-D ester applied PP may improve MHR horseweed control.

There is little information on the a) tolerance of white bean to tiafenacil herbicide mixtures with bromoxynil, metribuzin, halauxifen-methyl, 2,4-D ester, bromoxynil + metribuzin, bromoxynil + halauxifen-methyl, and bromoxynil + 2,4-D ester applied PP, and b) the efficacy of these herbicide mixtures for the control of MHR horseweed. The objective of this research was to ascertain the tolerance of white beans to tiafenacil herbicide mixtures and determine if MHR horseweed control with tiafenacil can be improved by adding herbicide partners in a surrogate soybean crop.

2. Materials and Methods

For the research evaluating white bean tolerance, there were a total of 4 site-years (Table 1). For the study evaluating MHR horseweed control in the surrogate soybean crop, there were a total of 5 site-years (Table 2). The MHR horseweed control study was completed in soybean with a number of other soybean experiments. The authors are confident that the MHR horseweed control with tiafenacil in white bean would be very similar to the surrogate soybean crop since the herbicide mixtures were applied PP to emerged horseweed before the crop was seeded and the surrogate soybean crop was seeded in rows spaced 75 cm apart similar to white bean production.

Table 1. Year, location, soil characteristics, application weather conditions, application date, seeding date, and emergence date for experiments conducted in Ontario, Canada in 2021 and 2022

	Year	Location	Texture	Soil characteristics[a]					Application weather conditions			Application date	Seeding date	Emergence date
				Sand	Silt	Clay	Organic matter	pH	Air temperature	Relative humidity	Wind speed			
				---------------- % ---------------					C	%	km h^{-1}			
E1	2021	Exeter	Clay loam	32	40	28	4.6	7.9	14	48	2	May 14	May 19	May 26
E2	2021	Exeter	Clay loam	32	40	28	4.6	7.9	18.8	50.4	0.8	May 19	May 25	June 4
E3	2022	Ridgetown	Sandy loam	55	31	14	4.5	6.3	26.6	45.0	1.3	June 2	June 8	June 15
E4	2022	Ridgetown	Loam	39	41	20	4.6	6.2	24.1	47.9	5.8	June 14	June 21	June 28

Note. [a] Soil cores were extracted to a depth of 15 cm and analyzed by A&L Canada Laboratories Inc. (2136 Jetstream Road, London, ON) to determine soil characteristics.

Table 2. Year, location, soil characteristics, application weather conditions, application date, seeding date, and emergence date for MHR horseweed control experiments conducted in Ontario, Canada in 2021 and 2022

	Year	Location	Texture	Soil characteristics[a]					Application weather conditions			Application date	Seeding date	Emergence date
				Sand	Silt	Clay	Organic matter	pH	Air temperature	Relative humidity	Wind speed			
				---------------- % --------------					C	%	km h^{-1}			
E1	2021	Bothwell	Loamy sand	85	11	4	3.3	6.5	27.1	41.1	7.4	May 19	June 12	June 18
E2	2021	Ridgetown	Sandy loam	67	21	12	1.9	6.4	23.3	49.1	7.8	May 17	May 19	May 26
E3	2021	Moraviantown	Loamy sand	82	13	6	2.2	6.1	29.5	32.7	1.2	June 1	June 17	June 24
E4	2022	Zone Centre	Sandy	89	9	2	3.0	6.4	20.0	62.6	3.2	June 8	June 13	June 17
E5	2022	Clachan	Sandy loam	58	28	14	3.3	7.3	19.0	51.6	2.8	May 19	May 24	May 31

Note. [a] Soil cores were extracted to a depth of 15 cm and analyzed by A&L Canada Laboratories Inc. (2136 Jetstream Road, London, ON) to determine soil characteristics.

All experiments were arranged in a randomized complete block design (RCBD) with 3 or 4 replicates. Herbicide treatments for both studies included tiafenacil (25 g a.i. per ha^{-1}), tiafenacil + bromoxynil (25 + 280 g a.i. per ha^{-1}), tiafenacil + metribuzin (25 + 200 g a.i. per ha^{-1}), tiafenacil + halauxifen-methyl (25 + 5 g a.i. per ha^{-1}), tiafenacil + 2,4-D ester (25 + 528 g a.i. per ha^{-1}), tiafenacil + bromoxynil + metribuzin (25 + 280 + 200 g a.i. per ha^{-1}), tiafenacil + bromoxynil + halauxifen-methyl (25 + 280 + 5 g a.i. per ha^{-1}), and tiafenacil + bromoxynil + 2,4-D ester (25 + 280 + 528 g a.i. per ha^{-1}) (Table 3). The white bean tolerance study was maintained weed-free for the duration of the growing season. The MHR horseweed control study included a non-treated (weedy) and a weed-free control treatment. All tiafenacil herbicide treatments included glyphosate (900 g a.i. per ha^{-1}) and MSO® concentrate (0.5% v/v).

Table 3. Active ingredients, trade names, and manufacturers for experiments conducted [a]

Active ingredients	Trade name	Manufacturer
2,4-D ester	2,4-D Ester ___	Nufarm Agriculture Inc., Calgary AB
Bromoxynil	Pardner	Bayer CropScience Canada, Calgary, AB
Glyphosate	Roundup WeatherMAX	Bayer CropScience Canada, Calgary, AB
Halauxifen-methyl	Arylex	Corteva Agriscience Canada Company, Calgary, AB
Metribuzin	Sencor	Bayer CropScience Canada, Calgary, AB
Tiafenacil	Terrad'or	BASF Canada Inc., Mississauga, ON

Note. [a] Specimen labels for each product and manufacturer contact information can be found at https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php

For both studies, plots were 3.0 m wide and 8 or 10 m long. Each plot consisted of four rows of white bean 'T9905' (250,000 seeds per ha^{-1}) or glyphosate/dicamba-resistant soybean 'DKB 10-20'/'MK-0616-B2'/'RM-0817-A5' (400,000 seeds per ha^{-1}) seeded in rows that were spaced 75 cm apart to a depth of 4 cm on dates shown in Tables 1 and 2.

Herbicides were applied up to 10 days before planting for the tolerance study and when MHR horseweed was approximately 10 cm in diameter/height (1-12 days before planting) for the horseweed control study with a CO_2-pressurized backpack sprayer with a spray boom that was 1.5 m wide and had four ULD-120-02 nozzles spaced 0.5 m apart (spray width of 2.0 m) that was calibrated to deliver 200 L per ha^{-1} at 240 kPa.

For the experiment evaluating white bean tolerance, injury in white beans was rated at 1, 2, 4, and 8 weeks after white bean emergence (WAE) on a scale of 0 (no injury) to 100 (complete dry bean plant death). White bean plant stand (number per meter of row at 3 WAE) and aboveground dry biomass (dry weight per plant or meter of row at 3 WAE) and dry bean height (average height of 10 plants per plot in cm at 6 WAE) were measured. At harvest maturity the center two rows of each plot were harvested with a small plot combine, SM content and weight were recorded. White bean yields were adjusted to 18% SM content.

For the experiment evaluating horseweed control, soybean injury was rated at 2, 4, and 8 WAE based on the same scaling as the white bean study. MHR horseweed control was rated at 4 and 8 weeks after application (WAA) on a scale of 0 (no control) to 100 (complete control). MHR horseweed density and aboveground dry biomass were measured at 8 WAA by determining the number of MHR horseweeds in two randomly placed 0.25 m^2 quadrats in each plot, cutting them at ground level, drying them in an oven at 60 C and then weighing them. Soybean yield was measured at harvest maturity by harvesting each plot with a small plot combine, SM content and weight were recorded. Soybean yields were adjusted to 13% SM content.

For both studies, data were analyzed in software SAS® (2014). The fixed effect in Proc GLIMMIX was herbicide treatment, and the random effects were environment (year-location combinations), the treatment by environment interaction and replicate nested within environment. For the white bean tolerance study, the Gaussian distribution was used for all variables, and percent visible crop injury was arcsine square root transformed prior to analysis. For the study evaluating horseweed control, crop yield was analyzed using the Gaussian distribution and percent visible weed control was arcsine square root transformed. The lognormal distribution was utilized for the analysis of MHR horseweed density and dry biomass data. Treatments that had assigned values resulting in zero variance were excluded from the analysis; in the case of the value zero, comparisons were still possible by utilizing the P-value in the LSMEANS table. For presentation, least square means were back-transformed when necessary.

3. Results and Discussion

3.1 White Bean Tolerance Study

At 1 WAE, glyphosate + tiafenacil caused 1% white bean injury; the addition of bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D caused 2, 3, 3, and 8% white bean injury, respectively. Glyphosate + tiafenacil + bromoxynil caused 2% white bean injury; the addition of metribuzin, halauxifen-methyl, or 2,4-D caused 3, 3, and 8% white bean injury, respectively (Table 4).

Table 4. White bean injury, plant stand, dry biomass, height, seed moisture content at harvest, and yield for tiafenacil mixtures applied preplant at Exeter, ON in 2021 (n = 2) and Ridgetown, ON in 2022 (n = 2). Means followed by the same letter within a column are not significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$ [a]

Treatment[c]	Rate	White bean injury[b]				Stand	Dry biomass		Height	Moisture	Yield
		1 WAE	2 WAE	4 WAE	8 WAE						
	g a.i. ha^{-1}	---------------- %			------------------	# m^{-1}	g m^{-1}	g $plant^{-1}$	cm	%	T ha^{-1}
Non-treated control		0.0 a	0.0 a	0.0 a	0.0 a	17 a	18.1 a	1.1 a	48 a	17.6 a	3.58 ab
Tiafenacil	25	1.4 ab	2.1 b	0.9 ab	0.3 ab	17 a	16.5 a	1.0 a	48 a	17.3 a	3.69 ab
Tiafenacil + bromoxynil	25 + 280	1.6 ab	1.8 ab	0.9 ab	0.2 ab	17 a	16.3 a	1.0 a	48 a	17.5 a	3.73 a
Tiafenacil + metribuzin	25 + 200	2.5 b	3.0 b	2.0 b	1.3 bc	17 a	16.4 a	1.0 a	46 a	17.4 a	3.64 ab
Tiafenacil +halauxifen-methyl	25 + 5	2.9 b	3.7 b	2.7 b	3.4 bc	17 a	15.8 a	0.9 a	46 a	17.5 a	3.49 ab
Tiafenacil + 2,4-D ester	25 + 528	8.0 b	7.3 b	3.7 b	0.6 ab	17 a	15.6 a	0.9 a	47 a	17.7 a	3.63 ab
Tiafenacil + bromoxynil + metribuzin	25 + 280 + 200	2.9 b	3.6 b	3.1 b	2.5 bc	16 a	15.4 a	1.0 a	47 a	17.4 a	3.52 ab
Tiafenacil + bromoxynil + halauxifen-methyl	25 + 280 + 5	3.0 b	3.8 b	3.7 b	5.2 c	16 a	14.4 a	0.9 a	47 a	17.6 a	3.41 b
Tiafenacil + bromoxynil + 2,4-D ester	25 + 280 + 528	8.1 b	7.4 b	3.3 b	0.8 abc	16 a	16.6 a	1.0 a	48 a	17.6 a	3.58 ab

Note. [1] Abbreviations: WAE, weeks after crop emergence.

[b] No injury observed at one Ridgetown location in 2022; not included in the analysis due to zero variance.

[c] All herbicide treatments included glyphosate (900 g ae ha^{-1}) and MSO concentrate (0.5% v/v).

At 2 WAE, glyphosate + tiafenacil caused 2% white bean injury; the addition of bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D caused 2, 3, 4, and 7% white bean injury, respectively. Glyphosate + tiafenacil + bromoxynil caused 2% white bean injury; the addition of metribuzin, halauxifen-methyl, or 2,4-D caused 4, 4, and 7% white bean injury, respectively (Table 4).

At 4 WAE, glyphosate + tiafenacil caused 1% white bean injury; the addition of bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D caused 1, 2, 3, and 4% white bean injury, respectively. Glyphosate + tiafenacil + bromoxynil caused 1% white bean injury; the addition of metribuzin, halauxifen-methyl, or 2,4-D caused 3, 4, and 3% white bean injury, respectively (Table 4).

At 8 WAE, glyphosate + tiafenacil caused 0% white bean injury; the addition of bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D caused 0, 1, 3, and 1% white bean injury, respectively. Glyphosate + tiafenacil +

bromoxynil caused 0% white bean injury; the addition of metribuzin, halauxifen-methyl, or 2,4-D caused 3, 5, and 1% white bean injury, respectively (Table 4).

At 3 WAE, none of the herbicide treatments evaluated reduced white bean stand, biomass^{-1}, or biomass plant^{-1} relative to the control (Table 4). At 6 WAE, none of the herbicide treatments evaluated reduced white bean height relative to the control (Table 4).

At harvest maturity, there was no effect of the herbicide treatments evaluated on white bean maturity as indicated by SM content at harvest. Additionally, there was no effect of the herbicide treatments evaluated relative to the control on white bean yield (Table 4).

Results are similar to other studies in which tiafenacil applied PRE at 25 g a.i. per ha^{-1} caused 0-4% injury in azuki, kidney, small red, and white bean and caused no adverse effect on plant stand, dry biomass, height, SM content, and yield (Soltani et al., 2021b). Sprague et al. (2020) also observed no visible injury, plant stand reduction, or yield reduction with tiafenacil applied PP at 24 g a.i. per ha^{-1} in black bean.

3.2 MHR Horseweed Control Study

At 2, 4, and 8 WAA, there was no soybean injury from the PP herbicides evaluated (data not shown). This is consistent with other studies conducted with glyphosate + tiafenacil or saflufenacil, another PPO-inhibitor herbicide applied PP in a mixture with other herbicides in soybean (Miller et al., 2012; Budd et al., 2016a, 2016b; Westerveld et al., 2021).

At 4 WAA, glyphosate + tiafenacil provided 40% control of MHR horseweed (Table 5). The co-application of glyphosate + tiafenacil with bromoxynil, metribuzin. halauxifen-methyl, or 2,4-D controlled MHR horseweed 52, 59, 94, and 75%, respectively. The co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D controlled MHR horseweed 78, 91, and 86%, respectively.

Table 5. Visible multiple herbicide-resistant horseweed control, density and dry biomass and soybean yield for tiafenacil mixtures applied preplant near Bothwell, Moraviantown, and Ridgetown, ON in 2021 (n = 3) and 2022 (n = 2). Means followed by the same letter within a column are not significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$ [a]

Treatment[b]	Rate	Horseweed control		Horseweed density	Horseweed dry biomass	Soybean yield
		4 WAA	8 WAA			
	g a.i. ha^{-1}	---------- % ---------		plants m^{-2}	g m^{-2}	T ha^{-1}
Weed-free control		100	100	0 a	0 a	2.08 a
Non-treated control		0 d	0 e	206 f	218 f	1.22 b
Tiafenacil	25	40 c	23 d	180 ef	161 ef	1.60 ab
Tiafenacil + bromoxynil	25 + 280	52 bc	33 d	160 de	179 ef	1.66 ab
Tiafenacil + metribuzin	25 + 200	59 bc	48 cd	78 bcd	155 cdef	1.86 ab
Tiafenacil +halauxifen-methyl	25 + 5	94 a	91 a	68 bcd	31 b	2.33 a
Tiafenacil + 2,4-D ester	25 + 528	75 ab	56 bcd	92 cde	93 bcd	1.83 ab
Tiafenacil + bromoxynil + metribuzin	25 + 280 + 200	78 ab	73 abc	43 b	149 bcde	2.08 a
Tiafenacil + bromoxynil + halauxifen-methyl	25 + 280 + 5	91 a	87 ab	49 bc	33 b	2.01 a
Tiafenacil + bromoxynil + 2,4-D ester	25 + 280 + 528	86 a	78 abc	45 b	91 bcd	2.04 a

Note. [1] Abbreviations: WAA, weeks after treatment application.

[b] All herbicide treatments included glyphosate (900 g ae ha^{-1}) and MSO concentrate (0.5% v/v).

At 8 WAA, glyphosate + tiafenacil provided only 23% control of MHR horseweed (Table 5). The co-application of glyphosate + tiafenacil with bromoxynil, metribuzin. halauxifen-methyl, or 2,4-D controlled MHR horseweed 33, 48, 91, and 56%, respectively. The co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D controlled MHR horseweed 73, 87, and 78%, respectively.

At 8 WAA, glyphosate + tiafenacil did not reduce MHR horseweed density relative to the weedy control (Table 5). However, the co-application of glyphosate + tiafenacil with bromoxynil, metribuzin. halauxifen-methyl, or 2,4-D reduced MHR horseweed denisty 22, 62, 67, and 55%, respectively. The co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D controlled MHR horseweed 79, 76, and 78%, respectively.

At 8 WAA, glyphosate + tiafenacil , bromoxynil, or metribuzin did not reduce MHR horseweed dry biomass relative to the weedy control however, glyphosate + tiafenacil + halauxifen-methyl, or 2,4-D reduced MHR horseweed dry biomass 86 and 57%, respectively (Table 5). The co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D reduced MHR horseweed dry biomass 32, 85, and 58%, respectively.

Results are similar to other studies in which glyphosate + tiafenacil alone or in combination with bromoxynil, dicamba, and tolpyralate applied PP provided 51-68%, 83-88%, 84-88%, and 83-90% control of MHR horseweed in corn, respectively (Soltani et al., 2021a). Haring and Hanson (2020) reported 71-84% control of GR horseweed with tiafenacil applied PP at 25, 50, and 75 g a.i. pha^{-1} in soybean. Westerveld et al. (2021) observed 55-66% GR horseweed control with glyphosate + tiafenacil (900 + 25 g a.i. per ha^{-1}) applied PP, and 87-90% GR horseweed control with glyphosate + tiafenacil + metribuzin (900 + 25 + 400 g a.i. per ha^{-1}) applied PP in soybean. Furthermore, GR horseweed density and dry biomass were decreased 39% and 42% with glyphosate + tiafenacil (900 + 25 g a.i. per ha^{-1}) applied PP and 94% and 63% with glyphosate + tiafenacil + metribuzin (900 + 25 + 400 g a.i. per ha^{-1}) applied PP in soybean, respectively (Westerveld et al., 2021). In other studies with corn, glyphosate (900 g a.i. per ha^{-1} + tiafenacil (25 g a.i. per ha^{-1}) applied PP decreased GR horseweed density 43%, and GR horseweed dry biomass 55% (Soltani et al., 2021a). Additionally, glyphosate (900 g a.e. per ha^{-1}) + tiafenacil (25 g a.i. per ha^{-1}) or co-applied with bromoxynil (280 g a.i. per ha^{-1}), dicamba (300 g a.i.per ha^{-1}), or tolpyralate (30 g a.i. per ha^{-1}) decreased GR horseweed density 43, 94, 89, and 91%, and GR horseweed dry biomass 55, 93, 98, and 98%, respectively (Soltani et al., 2021a).

MHR horseweed interference caused a 41% reduction in soybean yield in this study (Table 5). MHR interference with glyphosate + tiafenacil, bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D ester resulted in soybean yield that was similar to the non-treated (weedy) control; in contrast, reduced MHR horseweed interference with glyphosate + tiafenacil + halauxifen-methyl resulted in soybean yield that was similar to the weed-free control (Table 5). Reduced MHR horseweed interference with the co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D ester resulted in soybean yield that was similar to the weed-free control (Table 5). Similarly, Westerveld et al. (2021) reported a 67% seed yield reduction from GR horseweed interference in soybean. In the same study, reduced MHR horseweed interference with glyphosate + tiafenacil alone and co-applied with metribuzin resulted in soybean comparable yield that was similar to the weed-free control (Westerveld et al., 2021).

4. Conclusions

Results from this research indicate that all tiafenacil mixtures evaluated except those that include 2,4-D ester cause minimal (4% or less) injury in white bean with no adverse effect on white bean stand, dry biomass, height, SM content, or yield. Glyphosate + tiafenacil + 2,4-D ester and glyphosate + tiafenacil + bromoxynil + 2,4-D ester caused up to 8% injury in white bean but had no adverse effect on white bean stand, dry biomass, height, SM content, or yield. Glyphosate + tiafenacil alone or co-applied with bromoxynil, metribuzin, or 2,4-D controlled MHR horseweed 23-75%, reduced MHR horseweed density up to 62% and biomass up to 56%; soybean yield was similar to the non-treated control. Glyphosate + tiafenacil + halauxifen-methyl and the co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D ester controlled MHR horseweed 73-94%, reduced MHR horseweed density up to 79% and biomass up to 86%; soybean yield was similar to the weed-free control. In conclusion, among herbicide options evaluated, glyphosate + tiafenacil + halauxifen-methyl and the co-application of glyphosate + tiafenacil + bromoxynil with metribuzin, halauxifen-methyl, or 2,4-D ester provides the most consistent control of MHR horseweed.

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Authors Contributions

Drs. Peter Sikkema and Nader Soltani were responsible for the study design and writing of this manuscript. Christy Shropshire conducted the statistical analysis of the data collected.

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