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Sensitivity of Azuki Bean and Control of Multiple Herbicide-Resistant Canada Fleabane With Saflufenacil Herbicide Mixtures

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Abstract

During 2021 and 2022, four experiments were conducted to ascertain the sensitivity of azuki bean to saflufenacil herbicide mixtures, and five experiments were conducted to determine the control of multiple herbicide-resistant (MHR) Canada fleabane with various saflufenacil herbicide mixtures applied preplant (PP) in soybean at various locations in southwestern Ontario, Canada. At 1, 2, 4, and 8 weeks after emergence (WAE), glyphosate + saflufenacil caused 2-5% azuki bean injury. The addition of metribuzin, bromoxynil, halauxifen-methyl, or 2,4-D ester caused 2-7%, 2-4%, 4-9%, and 2-4% azuki bean injury, respectively. Glyphosate + saflufenacil + bromoxynil plus either metribuzin, halauxifen-methyl, or 2,4-D ester caused 3-7%, 5-11%, and 3-6% azuki bean injury, respectively. Saflufenacil mixtures evaluated had no adverse effect on azuki bean stand, biomass m^{-1}, biomass $plant^{-1}$, height, seed moisture content, or yield. At 4 and 8 weeks after application (WAA), glyphosate + saflufenacil control MHR Canada fleabane 93 and 87%, respectively; there was no improvement in MHR Canada fleabane control with the glyphosate + saflufenacil mixtures evaluated. At 8 WAA, saflufenacil herbicide mixtures evaluated reduced MHR Canada fleabane density 43-95% and biomass 47-96%; differences were not statistically significant. MHR Canada fleabane interference reduced soybean yield 50%; however, reduced MHR Canada fleabane interference with all glyphosate + saflufenacil mixtures evaluated resulted in soybean yield that was similar to the weed-free control. This study concludes that saflufenacil herbicide mixtures evaluated have the potential to be used for the control MHR Canada fleabane in azuki bean.

Keywords: Azuki bean stand, biomass, density, seed yield, *Vigna angularis* (Willd.) Ohwi & Ohashi, multiple herbicide resistance, efficacy

1. Introduction

Azuki bean is a small, dark red market class of dry bean from the *Vigna angularis* species produced for the export market to Asia. Azuki bean has a nuttier and sweeter flavor than the *Phaseolus vulgaris* L. species and is popular in Japan and other Asian countries for use in confectionery and culinary products (Petruzzello, 2023). The production of azuki bean is increasing in Ontario, it has increased from 3116 hectares in 2017 to almost 8094 hectares in 2019 (Greig, 2019). Azuki bean grows as a low bushy vine and is therefore vulnerable to competition from weeds (Petruzzello, 2023). The Yield Loss Committee of the Weed Science Society of America (WSSA) has reported that there would be a 71% yield loss in dry bean if weeds were left uncontrolled (Soltani et al., 2018). Multiple herbicide-resistant (MHR) weeds, especially MHR Canada fleabane, have become more prevalent in dry bean in recent years. A recent study estimated that MHR Canada fleabane is present in 30 counties and covers 5% of all field crop hectares in Ontario (Soltani et al., 2022). There are a limited number of herbicides available for the control of MHR Canada fleabane in azuki bean. Dry beans are known for their high sensitivity to numerous herbicides and therefore exhibit substantially greater injury than crops such as corn, soybean, or winter wheat when treated with herbicides. More research is required to identify new herbicide options that are safe for use in azuki bean and can provide effective control of MHR Canada fleabane.

Saflufenacil is a member of the pyrimidinedione chemical family, WSSA Herbicide Group 14, that can be applied preplant (PP) or pre-emergence (PRE) in many crops including corn, soybean, and wheat (Anonymous, 2008; Grossmann et al., 2010). Saflufenacil has both contact and residual activity. In susceptible plants, saflufenacil inhibits protoporphyrinogen-IX-oxidase (PPO), an enzyme needed for chlorophyll and heme biosynthesis (Liebl, 2008). Saflufenacil provides control broadleaf weeds including velvetleaf (*Abutilon theophrasti* Medicus), common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*Ambrosia trifida* L.), common cocklebur (*Xanthium strumarium* L.), ladysthumb (*Polygonum persicaria* L.), redroot pigweed (*Amaranthus retroflexus* L.), common waterhemp (*Amaranthus rudis* Sauer), common lambsquarters (*Chenopodium album* L.), Canada fleabane (*Erigeron canadensis* (L.) Cronq.), broadleaf plantain (*Plantago major* L.), shepherd's purse (*Capsella bursa-pastoris* L.), stinkweed (*Thlaspi arvense* L.), wild buckwheat (*Polygonum convolvulus* L.), and wild mustard (*Sinapis arvensis* L.) and suppression of perennial sowthistle (*Sonchus oleraceus* L.), prickly lettuce (*Lactuca serriola* L.), and dandelion (*Taraxacum Officinale* L.) (Anonymous, 2008; Liebl, 2008; Own et al., 2011). Additionally, earlier studies have shown that saflufenacil can control or suppress MHR weeds such as waterhemp, palmer amaranth, and Canada fleabane (Mellendorf et al., 2013). Furthermore, saflufenacil tankmixed with glyphosate and other partner herbicides applied PP can provide consistent burndown of emerged weeds such as MHR Canada fleabane in various crops (Liebl, 2008; Mellendorf et al., 2013; Soltani et al., 2020).

Limited information exists on the sensitivity of azuki bean to glyphosate + saflufenacil mixtures with metribuzin, bromoxynil, halauxifen-methyl, or 2,4-D ester applied PP and the efficacy of these mixtures for the control of MHR Canada fleabane. The addition of an effective herbicide mix partner may improve the level and consistency of MHR Canada fleabane control (Mellendorf et al., 2013; Budd et al., 2016a, 2016b). The aim of this research was to determine the sensitivity of azuki beans to glyphosate + saflufenacil herbicide mixtures and to determine if MHR Canada fleabane control with glyphosate + saflufenacil can be improved by adding herbicide partners in a surrogate soybean crop.

2. Materials and Methods

The study evaluating azuki bean sensitivity to saflufenacil herbicide mixtures included a total of 4 experiments conducted over a 2-year period (Table 1). For the study evaluating MHR Canada fleabane control in a surrogate soybean crop, there were a total of 5 experiments (Table 2). The MHR Canada fleabane control study was completed in soybean with a number of other soybean experiments. The authors are confident that the MHR Canada fleabane control with saflufenacil in azuki bean would be very similar to the surrogate soybean crop since the herbicide mixtures were applied PP to emerged Canada fleabane before the crop was seeded and the surrogate soybean crop was seeded in rows spaced 75 cm apart similar to azuki bean production.

Table 1. Year, location, soil characteristics, application weather conditions, herbicide application date, and azuki bean seeding, and emergence date for four experiments on the sensitivity of azuki bean to glyphosate + saflufenacil herbicide mixtures 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	16	45	2	May 14	May 19	May 28
E2	2021	Exeter	Clay loam	32	40	28	4.6	7.9	20	50	1	May 19	May 25	June 7
E3	2022	Ridgetown	Sandy loam	55	31	14	4.5	6.3	27	45	1	June 2	June 8	June 15
E4	2022	Ridgetown	Loam	39	41	20	4.6	6.2	24	48	6	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, herbicide application date, and azuki bean seeding, and emergence date for five experiments conducted on the control of multiple herbicide-resistant Canada fleabane 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			
				---------------- % ---------------					^{o}C	%	km h^{-1}			
E1	2021	Bothwell	Loamy sand	85	11	4	3.3	6.5	27	41	7	May 19	June 12	June 18
E2	2021	Ridgetown	Sandy loam	67	21	12	1.9	6.4	23	49	8	May 17	May 19	May 26
E3	2021	Moraviantown	Loamy sand	82	13	6	2.2	6.1	30	33	1	June 1	June 17	June 24
E4	2022	Zone Centre	Sandy	89	9	2	3.0	6.4	20	63	3	June 8	June 13	June 17
E5	2022	Clachan	Sandy loam	58	28	14	3.3	7.3	19	52	3	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 saflufenacil (25 g a.i. ha^{-1}), saflufenacil + metribuzin (25 + 400 g a.i. ha^{-1}), saflufenacil + bromoxynil (25 + 280 g a.i. ha^{-1}), saflufenacil + halauxifen-methyl (25 + 5 g a.i. ha^{-1}), saflufenacil + 2,4-D ester (25 + 528 g a.i. ha^{-1}), saflufenacil + bromoxynil + metribuzin (25 + 280 + 400 g a.i. ha^{-1}), saflufenacil + bromoxynil + halauxifen-methyl (25 + 280 + 5 g a.i. ha^{-1}), and saflufenacil + bromoxynil + 2,4-D ester (25 + 280 + 528 g a.i. ha^{-1}) (Table 3). All herbicide treatments included glyphosate (900 g ae ha^{-1}) and the adjuvant Merge (1 L ha^{-1}). The azuki bean sensitivity experiments were maintained weed-free for the duration of the growing season. The MHR Canada fleabane control study included a non-treated (weedy) and a weed-free control in each replicate.

Table 3. Active ingredients, trade names, and manufacturers of herbicides used in experiments conducted in Ontario, Canada in 2021 and 2022[a]

Active ingredients[b]	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	Elevore	Corteva Agriscience Canada Company, Calgary, AB
Metribuzin	Sencor	Bayer CropScience Canada, Calgary, AB
Saflufenacil	Eragon	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

[b] All herbicide treatments included glyphosate (900 g ae ha^{-1}) and Merge (1 L ha^{-1}).

Table 4. Effect of preplant glyphosate + saflufenacil herbicide mixtures on azuki bean injury, plant stand, dry biomass, height, percent moisture at harvest, and yield 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 Tukey-Kramer multiple range test at P < 0.05[a]

Treatment[c]	Rate	Azuki 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	11.3 a	0.6 a	37 a	13.6 a	2.41 a
Saflufenacil	25	2.3 ab	3.2 ab	4.6 abc	1.8 ab	17 a	10.9 a	0.6 a	36 a	13.7 a	2.34 a
Saflufenacil + metribuzin	25 + 400	3.8 b	4.7 bc	7.1 bcd	2.3 ab	15 a	10.2 a	0.7 a	36 a	13.7 a	2.36 a
Saflufenacil + bromoxynil	25 + 280	2.6 ab	3.6 ab	4.4 abc	1.7 ab	18 a	10.8 a	0.6 a	37 a	13.7 a	2.50 a
Saflufenacil + halauxifen-methyl	25 + 5	4.1 b	8.8 cd	8.1 cd	4.0 bc	17 a	10.2 a	0.6 a	37 a	13.8 a	2.49 a
Saflufenacil + 2,4-D ester	25 + 528	3.2 b	3.7 ab	3.4 ab	2.4 ab	16 a	10.1 a	0.6 a	37 a	13.7 a	2.49 a
Saflufenacil + bromoxynil + metribuzin	25 + 280 + 400	5.1 b	6.6 bcd	6.1 bc	2.8 abc	17 a	9.5 a	0.6 a	37 a	13.7 a	2.56 a
Saflufenacil + bromoxynil + halauxifen-methyl	25 + 280 + 5	7.1 b	9.6 d	11.0 d	5.1 c	15 a	9.1 a	0.6 a	35 a	13.8 a	2.38 a
Saflufenacil + bromoxynil + 2,4-D ester	25 + 280 + 528	3.4 b	4.1 b	6.2 bc	3.3 bc	17 a	10.0 a	0.6 a	34 a	13.7 a	2.43 a

Note. Abbreviations: WAE, weeks after crop emergence.

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

[c] All herbicide treatments included glyphosate (900 g ae ha^{-1}) and Merge (1 L ha^{-1}).

For both studies, plots were 3.0 m wide and 8 or 10 m long. Each plot consisted of four rows of azuki bean ‘ERIMO’ (230,000 seeds ha^{-1}) or glyphosate/dicamba-resistant soybean ‘DKB 10-20’/‘MK-0616-B2’/’RM-0817-A5’ (400,000 seeds 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 5 to 7 days before azuki bean planting for the sensitivity study and when MHR Canada fleabane was approximately 10 cm in diameter/height (2 to 23 days before planting) for the Canada fleabane 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 ha^{-1} at 240 kPa.

For the research evaluating azuki bean sensitivity to saflufenacil herbicide mixtures, azuki bean injury was visually assessed at 1, 2, 4, and 8 weeks after bean emergence (WAE) on a scale of 0 (no injury) to 100 (complete dry bean plant death). Azuki bean plant stand (number meter of row^{-1}) and aboveground dry biomass (dry weight plant^{-1} or dry weight meter of row^{-1}) were determined at 3 WAE, and azuki bean height (average height of 10 plants) was measured at 6 WAE. At harvest maturity, the center two rows of each plot were harvested with a small plot combine; seed moisture content and weight were recorded. Azuki bean yield was adjusted to 13% seed moisture content prior to statistical analysis.

For the study evaluating MHR Canada fleabane control, soybean injury was rated at 2, 4, and 8 WAE based on the same scaling as the azuki bean sensitivity study. MHR Canada fleabane control was visually assessed as an estimate of the biomass reduction relative to the control at 4 and 8 weeks after herbicide application (WAA) on a scale of 0 (no control) to 100 (complete control). MHR Canada fleabane density and aboveground dry biomass were measured at 8 WAA by determining the number of Canada fleabane plants 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 determined at harvest maturity by harvesting with a small plot combine; seed moisture content and weight were recorded. Soybean yields were adjusted to 13% seed moisture content prior to statistical analysis.

Data analysis was carried out using the GLIMMIX procedure in SAS (Ver. 9.4, SAS Institute Inc., Cary, NC) with P = 0.05 as the chosen level of significance. The model comprised the fixed effect of herbicide treatment and the random effects of year-location combinations (environment), treatment by environment interaction, and replicate nested within environment. All variables in the azuki bean sensitivity and MHR Canada fleabane control studies were analyzed using the Gaussian distribution except azuki bean moisture at harvest and MHR Canada fleabane density and dry biomass, which used the lognormal distribution. Additionally, MHR Canada fleabane control data were arcsine square root transformed prior to analysis. Any treatment that had zero variance due to assigned values was excluded from the analysis; however, by using P-values from the

LSMEANS output, comparisons with the value zero were possible. Least square means were back-transformed for presentation when necessary.

3. Results and Discussion

3.1 Azuki Bean Sensitivity Study

At 1, 2, 4, and 8 WAE, glyphosate + saflufenacil caused 2-5% injury in azuki bean. The addition of metribuzin, bromoxynil, halauxifen-methyl, or 2,4-D ester caused 2-7, 2-4, 4-9, or 2-4% azuki bean injury, respectively. Glyphosate + saflufenacil + bromoxynil + metribuzin caused 3-7% injury in azuki bean. Glyphosate + saflufenacil + bromoxynil + halauxifen-methyl caused 5-11% injury in azuki bean. Glyphosate + saflufenacil + bromoxynil + 2,4-D ester caused 3-6% injury in azuki bean. Generally, azuki bean injury increased from 1 to 4 WAE and then decreased by 8 WAE.

At 3 WAE, saflufenacil herbicide mixtures evaluated had no adverse effect on azuki bean stand, biomass g m^{-1}, or biomass $plant^{-1}$ compared to the control (Table 4). At 6 WAE, none of the herbicide treatments evaluated reduced azuki bean height relative to the control (Table 4). Similarly, there was no effect of the saflufenacil herbicide treatments evaluated on azuki bean maturity as indicated by seed moisture content at harvest time. In addition, all saflufenacil herbicide mixtures evaluated resulted in azuki bean yield that was similar to the non-treated control (Table 4).

Results are similar to other studies in which saflufenacil applied PRE at 25 and 50 g ai ha^{-1} was shown to cause 7-31% injury in azuki bean with no adverse effect on plant stand, shoot dry weight, height, and seed yield (Soltani et al., 2014). However, in other studies completed in Ontario, azuki bean injury was as much as 65% and the yield loss was as much as 66% with saflufenacil applied PRE at higher rates of 100 and 200 g ai ha^{-1} (Soltani et al., 2010). There was 65-100% yield loss in some dry bean cultivars in Brazil with saflufenacil applied PRE at 29.4 g ai ha^{-1} (Diesel et al., 2014). In another study, tiafenacil, another pyrimidinedione, PPO-inhibitor herbicide, applied PRE at 25 g ai ha^{-1} caused 0-4% injury in azuki, kidney, small red, and white beans and caused no adverse effect on plant stand, dry biomass, height, seed moisture content, and yield (Soltani et al., 2021).

3.2 MHR Canada Fleabane Control Study

At 4 WAA, there was 19-25% visible soybean injury with glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, and saflufenacil + bromoxynil + 2,4-D ester applied PP (Table 5). MHR Canada fleabane interference reduced soybean yield 50%. However, reduced MHR Canada fleabane interference with all glyphosate + saflufenacil herbicide mixtures resulted in soybean yield that was similar to the weed-free control (Table 5). Results are similar to other studies that have shown little injury in soybean or other market classes of dry bean with PP application of glyphosate + saflufenacil co-applied with metribuzin, bromoxynil, halauxifen-methyl or 2,4-D ester (Budd et al., 2016a, 2016b; Miller et al., 2012; Westerveld et al., 2021). In other studies, MHR Canada fleabane interference caused a soybean yield decrease of 41% (Soltani et al., 2023), 67% (Westerveld et al., 2021), 73% (Budd et al., 2016a), and 82% (Eubank et al., 2008). Furthermore, reduced MHR Canada fleabane interference with glyphosate + saflufenacil co-applied with metribuzin or 2,4-D ester resulted in soybean yield that was similar to the weed-free control (Budd et al., 2016a, 2016b).

Table 5. Effect of preplant glyphosate + saflufenacil herbicide mixtures on visible percent control, density and dry biomass of multiple herbicide-resistant Canada fleabane (MHRCF), soybean injury and yield at sites 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	MHRCF control		MHRCF density	MHRCF dry biomass	Soybean	
		4 WAE	8 WAE			Injury 4 WAE[c]	Yield
	g a.i. ha^{-1}	%		plants m^{-2}	g m^{-2}	%	T ha^{-1}
Weed-free control		100	100	0 a	0 a	0 a	1.99 a
Non-treated control		0 b	0 b	112 b	236 b	0 a	1.00 b
Saflufenacil	25	93 a	87 a	43 ab	90 b	21 b	1.57 ab
Saflufenacil + metribuzin	25 + 400	95 a	86 a	34 ab	126 b	19 b	1.63 a
Saflufenacil + bromoxynil	25 + 280	94 a	83 a	64 ab	71 ab	25 b	1.61 a
Saflufenacil + halauxifen-methyl	25 + 5	97 a	94 a	31 ab	38 ab	24 b	1.67 a
Saflufenacil + 2,4-D ester	25 + 528	95 a	90 a	6 ab	10 ab	20 b	1.82 a
Saflufenacil + bromoxynil + metribuzin	25 + 280 + 400	94 a	86 a	25 ab	31 ab	25 b	1.64 a
Saflufenacil + bromoxynil + halauxifen-methyl	25 + 280 + 5	95 a	88 a	38 ab	44 ab	23 b	1.60 a
Saflufenacil + bromoxynil + 2,4-D ester	25 + 280 + 528	98 a	93 a	14 ab	21 ab	23 b	1.61 a

Note. Abbreviations: MHRCF, multiple herbicide-resistant Canada fleabane; WAE, weeks after crop emergence.

[b] All herbicide treatments included glyphosate (900 g ae ha^{-1}) and Merge (1 L ha^{-1}).

[c] Injury observed at only one site in 2021; all sites with zero injury were excluded from analysis due to zero variance.

At 4 WAA, glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied PP provided 93-98% control of MHR Canada fleabane (Table 5); there was no difference in MHR Canada fleabane control among the glyphosate + saflufenacil herbicide mixtures evaluated.

At 8 WAA, glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied PP provided 87, 86, 83, 94, 90, 86, 88 and 93% control of MHR Canada fleabane, respectively (Table 5). There was no difference in MHR Canada fleabane control among the glyphosate + saflufenacil herbicide mixtures evaluated.

At 8 WAA, glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied PP reduced MHR Canada fleabane density 43-95% and biomass 47-96%, but differences were not statistically significant (Table 5).

Results are similar to other studies in which glyphosate + saflufenacil co-applied with metribuzin or 2,4-D ester controlled GR Canada fleabane 95-100% and reduced GR Canada fleabane density 97-98% and biomass 92-93% in soybean (Budd et al. 2016a, 2016b). Loux (2014) reported excellent control of GR Canada fleabane with glyphosate + saflufenacil co-applied with metribuzin or 2,4-D ester applied PP in soybean. Eubank et al. (2008) observed 66-99% control of GR Canada fleabane with glyphosate + 2,4-D and glyphosate + metribuzin in soybean. Saflufenacil + metribuzin applied PP was shown to decrease GR Canada fleabane density 96-97% and biomass 99% in soybean (Soltani et al., 2020). Dilliott et al. (2022) reported that glyphosate + halauxifen-methyl plus saflufenacil or metribuzin applied PP provided excellent (> 90%) control of GR Canada fleabane in soybean. Westerveld et al. (2021) reported that glyphosate + saflufenacil + metribuzin and glyphosate/dicamba + saflufenacil applied PP controlled MHR Canada fleabane 99-100% and resulted in MHR Canada fleabane density and biomass, and soybean yield that was similar to the weed-free control. Hedges et al. (2018) reported that glyphosate/dicamba + saflufenacil, glyphosate/dicamba + saflufenacil/dimethenamid-P, and glyphosate/dicamba + saflufenacil/imazethapyr applied PP controlled MHR Canada fleabane 99-98%, reduced density 98%, and biomass 99% and resulted in soybean yield that was similar to the weed-free control. In other studies, tiafenacil, another PPO-inhibitor herbicide, when co-applied with bromoxynil, metribuzin, halauxifen-methyl, or 2,4-D ester applied PP decreased MHR Canada fleabane density 22, 62, 67, and 55% in white bean, respectively (Soltani et al., 2023). However, glyphosate + tiafenacil + bromoxynil tankmixes with metribuzin, halauxifen-methyl, or 2,4-D ester controlled MHR Canada fleabane 79, 76, and 78%, respectively (Soltani et al., 2023).

4. Conclusions

Results from this study show that glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied preplant can cause injury in azuki bean but the injury is transient with no adverse effect on azuki bean stand, dry biomass, height, seed moisture content, or yield. Glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied preplant caused significant soybean injury (19-25%) in one of 5 experiments. However, the injury was transient and did not result in a significant yield reduction in soybean. Glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied preplant provided good to excellent control of MHR Canada fleabane in soybean. This study concludes that glyphosate plus saflufenacil, saflufenacil + metribuzin, saflufenacil + bromoxynil, saflufenacil + halauxifen-methyl, saflufenacil + 2,4-D ester, saflufenacil + bromoxynil + metribuzin, saflufenacil + bromoxynil + halauxifen-methyl, or saflufenacil + bromoxynil + 2,4-D ester applied preplant at rates evaluated have the potential to be used for the control of MHR Canada fleabane in azuki bean.

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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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