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Response of dry beans to tiafenacil applied preemergence

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Abstract

Tiafenacil is a new nonselective, protoporphyrinogen IX oxidase–inhibiting pyrimidinedione herbicide that is under consideration for registration to control grass and broadleaf weeds in corn, soybean, wheat, cotton, and other crops prior to crop emergence. The sensitivity of dry beans to tiafenacil is not known. Four field experiments were completed at Exeter and Ridgetown, ON, Canada, during the 2019 and 2020 growing seasons, to determine the sensitivity of azuki, kidney, small red, and white beans to tiafenacil applied preemergence (PRE) at 12.5, 25, 50, and 100 g ai ha^{-1}. Tiafenacil applied at 100 g ai ha^{-1} caused 5% or less injury to azuki, kidney, small red, and white beans: 0% to 3% injury to azuki bean; 1% to 5% injury to kidney bean; and 1% to 4% injury to both small red bean and white bean. Tiafenacil applied PRE at 12.5, 25, 50, and 100 g ai ha^{-1} caused up to 1%, 4%, 4%, and 5% visible dry bean injury, respectively, but had no negative effect on other measured growth parameters including seed yield. Crop injury was generally greatest when tiafenacil was appled at the 100 g ai ha^{-1} rate in dry beans. Generally, kidney, small red, and white bean were more sensitive to tiafenacil than azuki bean. Dry bean injury was persistent and increased with time with the greatest injury observed 8 wk after emergence. Tiafenacil applied PRE can be a useful addition to the current strategies to control grass and broadleaf weeds, especially glyphosate-resistant horseweed and amaranth species prior to bean emergence.

Introduction

Dry bean is a major legume crop produced in Canada and the United States. The majority of dry beans produced in Canada are exported to the United States, Europe, and Asia (Bedford 2021; Hensall District Co-operative 2020). In 2020, growers in Ontario produced approximately 218,000,000 kg of dry beans on 69,000 ha with an approximate value of Can$130,000,000 (OMAFRA 2021). The beans most commonly grown in Canada and the United States are botanically classified as *Phaseolus vulgaris*, however, other species of dry beans exist, including azuki bean (*Vigna angularis*; Hensall District Co-operative 2020). The most common dry bean market classes grown in Ontario in 2019 in descending order were white (navy; 25,074 ha, 47%), azuki (8,085 ha, 15%), kidney (6,713 ha,13%), cranberry (5,140 ha, 10%), black (4,285 ha, 8%), and other market classes (3,604 ha, 7%; Hensall District Co-operative 2020). In Michigan, similar bean classes are produced with white, black, and small red beans comprising 53%, 30%, and 6% of bean hectares, respectively, in 2019 (S. Bales, dry bean extension specialist, personal communication). Optimum dry bean husbandry practices are needed to maximize dry bean quality, yield, and profitability. Weed interference can cause significant yield losses in dry beans. The Weed Science Society of America evaluated yield loss due to weeds in dry bean growing states and provinces in North America and found an average of 74% dry bean yield loss if weeds were not controlled (Soltani et al. 2018). Few herbicides are currently registered for weed control in dry beans because of the low hectarage compared to other field crops. It is critical to identify new herbicide options for dry bean producers so they can continue to implement diversified, sustainable weed management practices for profitable crop protection and protect soil and water resources in Ontario and elsewhere.

Tiafenacil is a new nonselective, pyrimidinedione, contact herbicide developed by FarmHannong Co., Ltd., in Korea, that is under consideration for use in corn, soybean, wheat, cotton, and other crops to control both monocot and dicot weeds prior to crop emergence (Anonymous 2020; Park et al. 2018; Westerveld 2021). Tiafenacil is one of the most active protoporphyrinogen IX oxidase (PPO) inhibitor herbicides from the pyrimidinedione chemical family (Park et al. 2018). It can control troublesome weeds such as velvetleaf (*Abutilon theophrasti* Medic.), common purslane (*Portulaca oleracea* L.), *Amaranthus* species, and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.; Haring and Hanson 2020; Park et al. 2018). In particular, tiafenacil can be an effective option for managing herbicide-resistant (HR) weeds because it provides an alternative for the control/suppression of glyphosate-resistant (GR) weeds including GR palmer amaranth (*Amaranthus palmeri* S. Watson), GR horseweed

[*Conyza canadensis* (L.) Cronquist], and GR waterhemp (*Amaranthus tuberculatus* var. *rudis*; EPA 2020a, 2020b; Haring and Hanson 2020). In a recent study, Gao et al. (2021) reported that tiafenacil readily dissipates in the soil and can be a potential substitute for glyphosate for weed control in orchards. EPA (2020b) has also determined that tiafenacil is useful as an alternative herbicide for GR Palmer amaranth control in cotton, GR horseweed control in soybean and corn, and GR waterhemp control in soybean and corn. Tiafenacil degrades rapidly in the soil and water and has been generally shown to have a low risk to other organisms and the environment (EPA 2020a, 2020b). Tiafenacil is proposed for preplant (PP) and preemergence (PRE) burndown use in crops (EPA 2020a, 2020b).

Currently, tiafenacil is being considered for registration at 12.5 to 100 g ai ha^{-1} for PP burndown in various crops (Anonymous 2020). The suggested rate for tiafenacil use in dry bean crops is 25 to 75 g ai ha^{-1}. Westerveld (2021) reported comparable yield as the non-weedy plots with tiafenacil applied PP at 25 and 50 g ai ha^{-1} alone and in mixes with other herbicides in soybean. Similarly, another recent study has shown little injury with tiafenacil applied PP at 12.5, 25, and 37.5 g ha^{-1} in corn (Soltani et al. 2021). The response of various market classes of dry beans to tiafenacil is not known. Other studies have shown significant dry bean injury and seed yield decrease with saflufenacil, another pyrimidinedione herbicide with similar use patterns (Soltani et al. 2010).

Published information is limited on tolerance of azuki, kidney, small red, and white beans to tiafenacil. If tolerance is acceptable, tiafenacil can provide broad-spectrum control of emerged weeds, including GR biotypes, prior to dry bean emergence. The objective of this study was to assess the sensitivity of azuki, kidney, small red, and white beans to tiafenacil applied preemergence at 12.5, 25, 50, and 100 g ai ha^{-1}.

Materials and Methods

Four field experiments were established at the Huron Research Station near Exeter, ON, and at the University of Guelph Ridgetown Campus near Ridgetown, ON, in 2019 and 2020. The soil at the Exeter location was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained) consisting of 34% sand, 36% silt, 30% clay, and 3.6% organic matter, pH 8.0 in 2019; and 39% sand, 37% silt, 24% clay, and 4.3% organic matter, pH 7.9 in 2020. The soil at the Ridgetown location was a Watford/Brady sandy loam consisting of 48% sand, 28% silt, 24% clay, and 6.7% organic matter, pH 6.6 in 2019; and 49% sand, 31% silt, 20% clay, and 6.0% organic matter, pH 6.5 in 2020. Seedbed preparation at all sites consisted of fall moldboard plowing followed by seedbed preparation in the spring with a field cultivator with rolling basket harrows.

The experimental design was split-plot with four replications. The field layout consisted of the main plot factor, tiafenacil rate (as listed in Table 1, laid out as a randomized complete block design); the split-plot factor was dry bean type (as listed in Table 1). Plots were 6.0 m wide (eight rows spaced 0.75 m apart) and 10.0 m long at Exeter, and 8.0 m long at Ridgetown. Each plot consisted of two rows of azuki ('Erimo'), kidney ('Red Hawk'), small red ('Merlot'), and white ('T9905') beans. Azuki, kidney, small red, and white beans were seeded 3 to 4 cm deep in late May to early June at approximately 280,000, 190,000, 210,000, and 250,000 seeds ha^{-1}, respectively.

Herbicides were applied 1 to 2 d after seeding with a CO_2-pressurized backpack sprayer (2.5-m spray boom, with 6 ULD-120-02 nozzles spaced 0.5 m apart calibrated to deliver 200 L ha^{-1} water volume at 240 kPa), which produced a spray width of 3.0 m.

Visible dry bean injury (on a scale of 0 to 100 where 0 = no injury and 100 = complete death) was estimated at 1, 2, 4, and 8 wk after dry bean emergence (WAE). Dry bean plant stand (number per meter of row, 3 WAE), aboveground dry biomass (dry weight/meter of row, 3 WAE), and dry bean height (average of 10 plants/plot in centimeters, 6 WAE) were measured for each dry bean type evaluated. The yield of each dry bean type was determined by harvesting the two rows of each plot at dry bean harvest maturity. The moisture for harvested seeds was adjusted to 13% for azuki bean and 18% for other dry bean types.

Data analysis was conducted using SAS (2014) software, and the level of significance was set at 0.05. In the GLIMMIX procedure, the model fixed effect was tiafenacil rate; and random effects were location-years (environment), replicate within environment, environment by tiafenacil rate by dry bean type interaction, and tiafenacil rate by replicate within environment interaction. Analysis assumptions were checked using plots of studentized residuals, chi-square/degrees of freedom ratio, normal probability plot and Shapiro-Wilk statistic for potential distributions. Dry bean injury was arcsine square root transformed before analysis with a Gaussian distribution; this distribution was also used for analyzing plant stand, biomass per meter of row, average height, and crop yield. Dry bean biomass per plant and crop moisture at harvest were analyzed using the log-normal distribution. Least square means were subjected to a Tukey-Kramer adjustment for pairwise comparisons on the model scale. The untreated control was excluded from the analysis for variables where it was assigned a fixed value with zero variance. A comparison with the value 0 was still possible using the P-value associated with each treatment in the LSMEANS table output.

Results and Discussion

Dry Bean Type

Analysis of variance showed no significant interactions between the main effects of tiafenacil rate and dry bean type. Therefore, data are presented for each dry bean type averaged over tiafenacil rate and for each tiafenacil rate averaged over dry bean type. Averaged over tiafenacil rates, visible injury was less than 6% for all market classes of dry beans at all evaluation dates (Table 1). At 1, 4, and 8 WAE, tiafenacil caused greater injury in kidney, small red, and white bean than in azuki bean. Azuki bean dry biomass was as much as 36% lower per meter row compared with the other dry bean types. Azuki bean was as much as 13% shorter than the small red and white bean plants but had a comparable height to the kidney bean plants. Among the dry bean types evaluated, small red bean produced the largest seed yield (3290 kg ha^{-1}), white bean produced an intermediate yield (2850 kg ha^{-1}), and kidney (2270 kg ha^{-1}) and azuki bean (2210 kg ha^{-1}) had the lowest and similar seed yields (Table 1).

Tiafenacil Rate

Higher tiafenacil application rates did not increase visible injury over 6% at 1, 2, and 4 WAE; and there was no effect of tiafenacil on bean stand, biomass, height, seed moisture content or seed yield (Table 1). Tiafenacil caused greater bean injury at the higher rates although differences were not always statistically significant. Tiafenacil at 12.5, 25, 50, and 100 g ai ha^{-1} applied PRE caused 0%, 0%, 1%, and 4% bean injury at 1 WAE; 1%, 2%, 3%, and

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Table 1. Effect of tiafenacil applied preemergence.[a,b,c]

Main effects	Visible Injury[d]				Stand	Biomass		Height	Seed moisture content	Yield
	1 WAE	2 WAE	4 WAE	8 WAE						
Dry bean type	——————% ——————				# m row^{-1}	g m row^{-1}	g plant^{-1}	cm	%	t ha^{-1}
Azuki	0.2 a	3.0 b	0.1 a	0 a	17 a	29 b	1.6 a	45 a	14.4 a	2.21 c
Kidney	0.8 b	1.2 a	0.7 a	5.2 c	9 b	45 a	4.3 c	48 ab	16.5 b	2.27 c
Small red	1.0 b	2.9 b	2.2 b	4.1 b	17 a	45 a	2.5 b	52 c	18.0 c	3.29 a
White	1.4 b	3.0 b	1.5 b	4.0 b	16 a	42 a	2.4 b	50 bc	19.0 d	2.85 b
Bean P-value	0.0033	0.0051	0.0001	0.0382	<0.0001	<0.0001	<0.0001	0.0055	<0.0001	<0.0001
Tiafenacil rate (g ai ha^{-1})[e]										
0	0 a	0 a	0 a	0	15	43	2.8	49	17.1	2.63
12.5	0 a	1.0 b	0.1 a	0	15	41	2.7	49	17.1	2.62
25	0.1 ab	2.1 bc	0.7 b	4.2	15	40	2.7	49	16.9	2.64
50	1.4 b	2.8 c	1.8 c	3.9	15	40	2.6	48	17.0	2.68
100	3.6 c	4.7 d	2.8 c	5.2	14	37	2.6	49	17.2	2.71
Rate P-value	<0.0001	0.0004	<0.0001	0.1644	0.0988	0.2007	0.5009	0.9997	0.9645	0.9817
Interaction										
Bean × rate P-value	0.1923	0.7084	0.2408	0.8371	0.9557	0.9165	0.2296	1.0000	1.0000	1.0000

[a]Abbreviations: Bean, dry bean type; rate, tiafenacil rate; WAE, weeks after crop emergence.
[b]Means followed by the same letter within a column are not significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.
[c]Means for a main effect were separated only if the interaction involving the main effects was negligible.
[d]Means for injury 1, 2, and 4 WAE are based on data from Exeter in 2019 and 2020; injury 8 WAE based on data from Exeter in 2019 only. All remaining site-years showed no visible injury and were excluded from analysis due to zero variance.
[e]All tiafenacil treatments included methylated seed oil (0.5% vol/vol). Untreated control excluded from analysis due to zero variance; comparison of herbicide treatments with the value zero obtained using LSMEANS table from the GLIMMIX procedure.

5% bean injury at 2 WAE; and 0%, 1%, 2%, and 3% bean injury at 4 WAE, respectively. Crop injury levels are in contrast to other studies of other pyrimidinedione herbicides such as saflufenacil, which has been shown to cause 51%, 92%, and 90% injury in azuki, cranberry, and white bean, respectively, when applied PRE at 100 g ai ha^{-1} (Soltani et al. 2010). Other studies have shown variable injury with other PPO inhibitors such as fomesafen, flumioxazin, and sulfentrazone in dry beans (Hekmat et al. 2007; Sikkema et al. 2009; Soltani et al. 2005). Sikkema et al. (2009) reported 1% visible injury with PRE application of fomesafen in dry beans. However, Hekmat et al. (2007) found as much as 30% injury with sulfentrazone applied PRE in eight different dry bean types. Flumioxazin was also shown to cause as much as 34% visible injury in black, cranberry, kidney, and white beans (Soltani et al. 2005).

These findings are in contrast with those reported by Sprague et al. (2020), showing 0%, 5%, 14%, and 19% visible injury at 14 d after planting (DAP); 0%, 2%, 6%, and 13% at 21 DAP; and 0%, 0%, 1%, and 13% injury at 35 DAP in 'Zorro' black beans with tiafenacil applied PP at 24, 47, 71, and 95 g ai ha^{-1}, respectively. The same research found that other pyrimidinedione herbicides such as saflufenacil can cause 74% to 78% injury at 24 g ai ha^{-1} and 96% to 98% injury at 48 g ai ha^{-1} in black bean (Sprague et al. 2020). Sprague et al. (2020) also showed that black bean stand was not adversely affected by tiafenacil at 24 and 47 g ai ha^{-1} but was decreased 21% at 71 g ai ha^{-1} and 29% at 95 g ai ha^{-1}. Tiafenacil did not shorten beans or reduce seed yield compared with the untreated control. Like our research, black bean seed yield was not decreased with tiafenacil applied PP at 24, 47, 71, and 95 g ai ha^{-1} (Sprague et al. 2020). The lower crop injury levels observed with dry bean types in this study compared to the black bean (Sprague et al. 2020) may be attributed to variations in the genetic pools of dry bean types being evaluated because they have different geographic origins and therefore have a different genetic pool that can impact their responses to herbicides (Renner and Powell 2002; Singh et al. 1991a, 1991b, 1991c).

Results from this study indicate that tiafenacil applied PRE at 12.5, 25, 50, and 100 g ha^{-1} can cause some minor injury in azuki, kidney, small red, and white dry beans, and the injury was persistent with highest levels observed 8 WAE. Bean injury increased as the rate of tiafenacil increased with the greatest injury from tiafenacil applied PRE at 100 g ai ha^{-1}. Visible injury was similar in small red and white beans, which were more sensitive to tiafenacil than azuki beans; kidney bean injury was variable in this study. Tiafenacil had no negative effect on the other growth parameters measured including the final seed yield. This study shows that tiafenacil applied PRE at the proposed rates of 25 to 75 g ai ha^{-1} can cause minor injury in dry beans and further research should be completed to verify this initial study, in addition to testing other dry bean market classes. Tiafenacil applied PRE with its unique characteristics can be a useful addition to the current weed control strategies for grass and broadleaf weed suppression/control, especially GR horseweed, prior to bean emergence. Further research is needed to determine the optimum tank mix partner with tiafenacil to extend and expand the range of weeds controlled prior to bean emergence. Herbicide tank mixtures with different sites of action may help decrease selection pressure for HR weeds.

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