Weed Science

www.cambridge.org/wsc

Agronomic predictors of herbicide-resistance in horseweed (*Erigeron canadensis*) for proactive management in Michigan

Juliano R.M. Sulzback[1], Eric L. Patterson[2] and Erin E. Burns[2]

[1]Graduate Student, Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI, USA and [2]Assistant Professor, Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI, USA

Research Article

Cite this article: Sulzback JRM, Patterson EL, Burns EE (2025). Agronomic predictors of herbicide-resistance in horseweed (*Erigeron canadensis*) for proactive management in Michigan. Weed Sci. **73**(e27), 1–9. doi: 10.1017/wsc.2025.6

Received: 17 June 2024
Accepted: 29 January 2025

Associate Editor:
William Vencill, University of Georgia

Keywords:
Auxinic herbicides; *Conyza canadensis*; glyphosate; herbicide-resistance evolution; multiple resistance; resistance spectrum

Corresponding author:
Erin E. Burns; Email: burnser5@msu.edu

Abstract

Herbicide-resistant weeds threaten modern agriculture production. In Michigan, horseweed [*Erigeron canadensis* L.; syn.: *Conyza canadensis* (L.) Cronq.] is among the most troublesome weeds, and glyphosate was widely used to control *E. canadensis*. Due to extreme selection pressure imposed by heavy glyphosate usage, glyphosate-resistant *E. canadensis* is widespread. New technologies to control resistant *E. canadensis* are being introduced in the form of multiple herbicide resistance traits integrated into glyphosate-resistant soybean [*Glycine max* (L.) Merr.] (e.g., dicamba or 2,4-D choline). These new soybean varieties will likely increase the use of 2,4-D and dicamba, thus increasing the resistance selection pressure in *E. canadensis*. Predicting agronomic factors that drive herbicide-resistance evolution can serve as an effective proactive tool to advise practitioners to modify management strategies. Therefore, the objectives of this study are: (1) conduct dose–response assays to assess the current resistance spectrum of *E. canadensis* collected in Michigan and (2) predict and determine the main factors in row-crop production that contribute to resistance evolution in these accessions. Dose–response assays were conducted to evaluate the herbicide sensitivity spectrum to glyphosate, dicamba, and 2,4-D in 20 *E. canadensis* accessions collected from eight Michigan counties. Out of the 20 accessions, 60% were resistant to glyphosate, 35% to 2,4-D, and 20% to dicamba. Pearson's correlation coefficient of dose–response values was positive in all comparisons (2,4-D-dicamba, $r = 0.35$; dicamba-glyphosate, $r = 0.15$; 2,4-D-glyphosate, $r = 0.21$). Dose–response data were integrated in odds ratio analyses to access the influence that previous management history had on the occurrence of resistance. Out of the significant pairwise comparisons, 44% were related to crop rotation frequency, 33% to previous herbicide-resistance status, and 22% to location where collected. Results highlight that growers have the ability to proactively manage herbicide-resistance evolution progression of *E. canadensis* in Michigan by adopting integrated weed management techniques to slow successive selection events that occur in low-diversity management systems.

Introduction

Horseweed [*Erigeron canadensis* L.; syn.: *Conyza canadensis* (L.) Cronq.] is an agriculturally important weed worldwide (Holm et al. 1997). In the United States, it is found in annual and perennial crops, such as soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), orchards, and vineyards (Moretti et al. 2016; Steckel and Gwathmey 2009). *Erigeron canadensis* competition can reduce yield by 32% to 69% in corn (Ford et al. 2014; Soltani et al. 2021) and 40% to 90% in soybean (Agostinetto et al. 2018; Trezzi et al. 2013; Weaver 2001). Furthermore, *E. canadensis* is difficult to control due to numerous factors. First, *E. canadensis* is the most widespread glyphosate-resistant weed in the world and it is also resistant to other common sites of action (SOAs) such as acetolactate synthase (ALS) inhibitors (Heap 2014). Second, *E. canadensis* has an extremely aggressive root system, and plants can grow up to 2.30-m tall (Bhowmik and Bekech 1993; Weaver 2001). Third, *E. canadensis* is a highly prolific seed producer; a single plant can produce up to 200,000 windblown seeds per year (Bhowmik and Bekech 1993; Weaver 2001). Wind-mediated seeds can travel long distances and infest a wide variety of different crops, even if they are relatively distant (Shields et al. 2006), which helps to explain the cosmopolitan nature of this species (Heap 2014; Holm et al. 1997). Fourth, *E. canadensis* can emerge in either the fall or spring, making it both a summer and winter annual, depending on environmental conditions (Schramski et al. 2021). Taken together, these traits make *E. canadensis* one of the most troublesome weed species (Van Wychen 2024).

Glyphosate has been widely used to control *E. canadensis* in both the fall and spring as part of burndown herbicide programs as well as in postemergence in-season applications to glyphosate-resistant crops (i.e., Roundup Ready®). Glyphosate-resistant *E. canadensis* was reported in the

© The Author(s), 2025. Published by Cambridge University Press on behalf of Weed Science Society of America. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

early 2000s, shortly after the widespread adoption of glyphosate-resistant crops, and is among the first glyphosate-resistant species identified (VanGessel 2001). Due to the extreme selection pressure imposed by heavy glyphosate usage, glyphosate-resistant *E. canadensis* became frequent and has rapidly spread across the United States, limiting the effective use of this chemistry and therefore glyphosate-resistant crop technology (Davis et al. 2008; Flessner et al. 2015; Heap 2023; Koger et al. 2004). In addition to glyphosate resistance, resistance to ALS, photosystem I (PSI), and photosystem II (PSII) inhibitors has been identified in *E. canadensis* accessions in the United States (Heap 2023; Moretti et al. 2021). Several of these accessions are resistant to two SOAs, termed multiple resistant. To date, multiple resistant *E. canadensis* accessions include resistance to: glyphosate and ALS inhibitors, glyphosate and PSI inhibitors, and triazine and ALS inhibitors (Byker et al. 2013; Davis et al. 2009; Matzrafi et al. 2015; Moretti et al. 2013). Specifically in Michigan, glyphosate-resistant *E. canadensis* accessions were first reported in 2007 in Mason County and have since become widespread, commonly in combination with ALS inhibitors (Hill 2024).

New technologies to control resistant accessions of *E. canadensis* are currently being introduced in the form of multiple herbicide resistance traits into glyphosate-resistant crops. Specifically, in soybean, new varieties include: Roundup Ready 2 Xtend® (glyphosate and dicamba resistant, Bayer Crop Science, St. Louis, Missouri, USA), Roundup Ready 2 XtendFlex® (glyphosate, dicamba, and glufosinate resistant, Bayer Crop Science, St. Louis, Missouri, USA), Enlist E3™ (2,4-D choline, glyphosate, and glufosinate resistant, Corteva Agriscience, Indianapolis, IN, USA) and LibertyLink GT27® (glyphosate, glufosinate, and isoxaflutole resistant, BASF, Ludwigshafen, Germany). Roundup Ready 2 Xtend® was first commercially available in 2017, while Enlist E3™ was first available in 2020 (Dodson 2022). The introduction of these multiple herbicide resistant soybean varieties primarily enables farmers to apply auxin-mimicking herbicides (Group 4) after soybean emergence. These new soybean varieties will likely increase the use of 2,4-D or dicamba for in-season weed control in soybean. Auxinic herbicide use is not unique in Michigan cropping systems, as these herbicides are commonly used in corn and wheat (*Triticum aestivum* L.) (Supplementary Table S1 in Supplementary File 1). Therefore, *E. canadensis* accessions within the state have already been exposed to auxinic herbicides, and additional recurrent use of these herbicides will increase the selection pressure for auxin resistance in *E. canadensis*.

Due to the insurgence of herbicide-resistant *E. canadensis* in the United States, especially in a relatively short time frame (Holm et al. 1997; VanGessel 2001), and considering new crop-resistant technologies, we are in critical need of information pertaining to the main contributing factors that select for resistance and how growers can alter use practices to delay resistance evolution. One approach is to use epidemiology theory to proactively—not reactively—predict and manage herbicide-resistance evolution (Comont et al. 2019; Comont and Neve 2021). A epidemiological understanding of the main drivers of herbicide-resistance evolution would permit us to educate growers and the agricultural industry as early as possible on how to avoid herbicide-resistance evolution and preserve the use of Group 4–resistant crops (Evans et al. 2016). Therefore, the objectives of this study are: (1) conduct dose–response assays to assess the current resistance spectrum of *E. canadensis* accessions to glyphosate, dicamba, and 2,4-D collected in Michigan; and (2) predict and determine the main factors in row-crop production that contribute to herbicide-resistance evolution in these accessions.

Materials and Methods

Dose–Response Assay

Greenhouse dose–response experiments were conducted from August 2021 to September 2023 at Michigan State University in East Lansing, MI, USA. The experimental design consisted of a randomized complete block design with four replications repeated twice. We utilized 20 *E. canadensis* accessions in this study collected from eight counties in Michigan (Table 1). Within an accession, seeds from multiple plants were hand threshed, cleaned, and pooled for the remaining analysis. Once cleaned, the accessions were planted in flats containing potting medium and placed in the greenhouse (16-h light at 26 C; 8-h dark at 18 C). When two true leaves were present, each plant was transplanted into a 12 by 12 cm pot (Shuttle Pot®, East Jordan Plastics, East Jordan, Michigan, USA) containing the same medium. When transplants reached approximately 12 cm in diameter, herbicide treatments were made. Plants were watered daily and fertilizer (NPK, 15-07-25, ICL Specialty Fertilizers, Summerville, South Carolina, USA) was applied weekly.

The dose–response experiment consisted of nine rates of the following herbicides: glyphosate (Roundup PowerMAX® 3, 575 g ae L^{-1}, Bayer Crop Science, St. Louis, Missouri, USA), dicamba (XtendiMax®, 350 g ae L^{-1}, Bayer Crop Science, St. Louis, Missouri, USA), and 2,4-D choline (Enlist One™, 455 g ae L^{-1}, Corteva Agriscience Indianapolis, IN, USA) (Table 1). For glyphosate, the dose treatments were: 0, 0.25, 0.5, 1, 2, 4, 8, 16, and 32 times the recommended labeled rate of 1.26 kg ae ha^{-1}. For dicamba and 2,4-D, the dose treatments were: 0, 0.016, 0.031, 0.062, 0.125, 0.25, 0.33, 0.5, and 1 times the recommended labeled rates of 0.56 kg ae ha^{-1} and 1.07 kg ae ha^{-1}, respectively. Additionally, 2% v/v dry ammonium sulfate was included with glyphosate and 2,4-D treatments. Herbicide treatments were applied using a single-track sprayer (Generation 4, DeVries Manufacturing, Hollandale, MN) equipped with an 8001E TeeJet® flat-fan nozzle (TeeJet® Technologies, Wheaton, IL) calibrated to deliver 187 L ha^{-1} at 193 kPa of pressure. Visual injury ratings were performed at 7, 14, and 21 d after treatment (DAT). Aboveground dry biomass was obtained at 21 DAT. Plants were cut at the soil surface and dried at 66 C for 7 d before dry biomass was recorded.

Statistical Analysis

Three- and four-parameter log-logistic models as well as a three-parameter Weibull model were fit to the data to determine the pattern of biomass reduction per herbicide and accession (Equations 1–3), where the independent variable was herbicide rate, and the dependent variable was dry biomass using the DRC package in R (Ritz et al. 2015). Model fit was assessed using the DRC *modelFit* function in R, following the methods outlined in Knezevic et al. (2007). Models that have P-values >0.05 were chosen for the analysis with a few exceptions in which models that yielded the smallest SE values were chosen for analysis (Table 2).

$$f(x) = \frac{d}{1 + \left[\frac{x}{(\mathrm{ED50})b}\right]} \quad [1]$$

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

Table 1. Mean herbicide dose required for 50% biomass reduction (ED_{50}) in 20 *Erigeron canadensis* accessions collected from eight counties in Michigan.

Accession location	ED_{50}[a]		
	Glyphosate	Dicamba	2,4-D
	kg ae ha^{-1}		
Cass	1.85 (1.34)	0.02 (0.00)	>1.07
Delta	<0.32	0.04 (0.04)	0.02 (0.62)
Ingham	<0.32	0.01 (0.49)	0.11 (0.55)
Ingham	<0.32	>0.56	>1.07
Ingham	<0.32	0.07 (0.13)	0.78 (0.13)
Ingham	4.75 (3.27)	0.03 (0.01)	1.03 (0.48)
Ingham	<0.32	<0.01	<0.02
Isabella	<0.32	0.05 (0.03)	>1.07
Isabella	1.15 (0.75)	>0.56	0.29 (0.24)
Isabella	6.53 (2.98)	<0.01	0.26 (0.04)
Macomb	>40.32	0.05 (0.06)	>1.07
Midland	3.59 (2.69)	0.13 (0.08)	0.33 (0.17)
Montcalm	0.38 (0.33)	0.03 (0.01)	0.22 (0.20)
Montcalm	2.79 (1.47)	0.33 (0.13)	>1.07
Montcalm	3.76 (2.89)	>0.56	>1.07
Montcalm	2.92 (0.53)	0.04 (0.04)	0.02 (0.01)
Montcalm	9.46 (20.28)	<0.01	0.81 (0.52)
Montcalm	14.25 (20.75)	0.49 (1.01)	0.48 (0.11)
Montcalm	>40.32	>0.56	>1.07
Saginaw	28.82 (19.19)	0.06 (0.03)	<0.02

[a]ED_{50} calculated using dry plant biomass harvested 21 d after treatment using the DRC package in R. Values in parentheses are ±SE. Field-recommended labeled rates are 1.26, 0.56, and 1.07 kg ae ha^{-1} for glyphosate, dicamba, and 2,4-D, respectively.

$$f(x) = d + \frac{(a-d)}{1+\left[\frac{x}{(\mathrm{ED50})b}\right]} \quad [2]$$

$$f(x \mid c, \lambda, k) = 1 - e^{\left[\frac{(x-c)^k}{\lambda}\right]} \quad [3]$$

For all the equations, $f(x)$ represents the effect of the herbicide at a given dose x, a is the response level when the dose x is the highest, d is the response level when the dose x is the lowest, ED_{50} is the dose causing 50% biomass reduction, and b is Hill's slope, which is how steep the dose–response curve is (Muse et al. 2021). For the Weibull function, $f(x/c, \lambda, k)$ is the probability that the ED_{50} is either less than or equal to a given dose x, c is the location parameter, λ is the scale parameter, and k is the shape parameter (Hallinan 1993). Accessions with ED_{50} values greater than the glyphosate recommended field use rate were considered resistant, and those with values lower than the field use rate were considered susceptible for subsequent analysis (Supplemental Fig. S1 in Supplementary File 1). Accessions with ED_{50} values greater than dicamba and 2,4-D recommended field use rates were considered to have reduced sensitivity, and those with values lower than field use rate were considered susceptible for subsequent analysis.

To investigate the association among ED_{50} values from different herbicides, correlation analysis was performed using Pearson's correlation coefficient (Equation 4) using the HMISC package in R (Harrell 2023).

$$r = \frac{(n\sum xy) - (\sum x) * (\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2] \cdot [(n\sum y^2 - (\sum y)^2]}} \quad [4]$$

For this equation, r represents the correlation coefficient, x and y represent the individual data points for ED_{50} values to be correlated, and x^2 and y^2 represent the average of the respective sets of ED_{50} values. Pearson's correlation coefficient (r) ranges from −1 to 1 (negative and positive correlation, respectively), where a value of: 0 indicates no; $0 < r < \pm 0.20$, weak; $\pm 0.20 < r < \pm 0.40$, moderate; $\pm 0.40 < r < \pm 0.80$, strong; and $\pm 0.80 < r < \pm 1.00$, very strong correlation (Pearson 1895).

Dose–response data were further analyzed using logistic regression (odds ratios) to access the influence previous management history had on the occurrence of resistant accessions using the *glm* function in R with bionomial family and logic link function (R Development Core Team 2021). Odds ratio analysis was performed to verify the strength and direction of association between two variables following the methods of Hailpern and Visintainer (2003). Further, logistic regression using odds ratios is robust for this type of data, as it makes no assumptions of variable distribution and provides valid model estimates irrespective of study design (Harrell 2015). For this study, odds ratio analyses were performed using the herbicide ED_{50} values (glyphosate, dicamba, and 2,4-D) generated in the dose–response assays in objective 1, location the accession was collected, previous herbicide-resistance screening, and 8-yr crop rotation history in the location where the accessions were collected (Table 3). Michigan State University Plant and Pest Diagnostics previously evaluated these accessions for herbicide response (screened with one and four times the recommend field use rate) to glyphosate, 2,4-D amine, and cloransulam (Hill 2024). Crop rotation data from 2015 to 2022 were collected from the USDA-NASS Cropland Data Layer using the CroplandCROS web application (USDA-NASS 2022). Once crop rotation information was extracted, the frequency of a particular crop grown in that rotation was calculated for each rotation and categorized as: high (greater than 50% of the years contained that crop), medium (20% to 50% of the years contained that crop), and low (less than 20% of the years contained that crop).

Results and Discussion

Dose Response

Glyphosate

Out of the 20 *E. canadensis* accessions evaluated in this study, 12 (60%) were resistant to glyphosate (i.e., survived the recommended field use rate of 1.26 kg ae ha^{-1}) (Table 1). Susceptible accession ED_{50} values varied substantially, ranging between <0.32 kg ae ha^{-1} (the lowest dose applied) to 1.15 kg ae ha^{-1} (~0.9 times the field use rate). Half of the susceptible accessions were collected from separate specific locations but within Ingham County, while the remaining accessions were distributed across Montcalm, Isabella, and Delta counties. Resistant accession ED_{50} values also varied widely, ranging between 1.85 kg ae ha^{-1} (1.5 times the field use rate) to >40.32 kg ae ha^{-1} (the highest rate applied). The accessions with ED_{50} values >40.32 kg ae ha^{-1} were collected from Macomb and Montcalm counties. Interestingly, out of the seven accessions collected in Montcalm County, six were resistant to glyphosate, with ED_{50} values ranging from 2.79 to >40.32 kg ae ha^{-1}.

Adopting Roundup Ready® (i.e., glyphosate-resistant) soybean simplified weed management, was economical, and saved growers multiple passes through the field for weed management. The adoption rate of Roundup Ready® soybean increased dramatically since introduction in 1996, reaching nearly 90% of acreage in the United States by 2008 (Dodson 2022). Michigan has followed suit, with 93% of soybean and 92% of corn hectarage being Roundup Ready® (USDA-NASS 2023). Annual glyphosate usage in Michigan is approximately 8.06 and 6.43 million L in soybean and corn, respectively. In the short term, this single-SOA weed control tactic allowed for higher yields with greatly reduced cost (Duke and

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

Table 2. List of statistical models used to generate mean herbicide dose required for 50% biomass reduction (ED_{50} in kg ae ha^{-1} ± SE) in 20 *Erigeron canadensis* accessions collected from eight counties in Michigan.[a]

	Model			Model fit		
Accession location	Glyphosate	Dicamba	2,4-D	Glyphosate	Dicamba	2,4-D
	Function			P-value		
Cass	LL.3	LL.4	LL.3	0.99	0.42	0.007
Delta	LL2.3	LL.4	LL.4	0.15	0.31	0.48
Ingham	LL.4	LL.3	LL2.3	0.98	0.29	0.96
Ingham	W1.3	LL.3	LL2.3	0.03	0.08	0.38
Ingham	LL.3	LL.3	LL.3	0.06	0.89	0.61
Ingham	LL.4	LL.4	LL.3	0.93	0.17	0.09
Ingham	W1.4	W2.3u	LL2.3	0.73	0.26	0.71
Isabella	LL.4	LL.4	LL.3	0.26	0.32	0.99
Isabella	LL.3	LL2.3	LL.3	0.79	0.06	0.84
Isabella	LL.4	LL2.4	LL.4	0.64	0.65	0.83
Macomb	LL.3	LL.4	LL2.3u	0.99	0.98	0.11
Midland	LL2.3	LL.3	LL.3	0.11	0.14	0.03
Montcalm	LL.4	LL.4	LL.3	0.60	0.23	0.95
Montcalm	LL.4	LL.3	LL.3	0.04	0.91	0.14
Montcalm	LL.3	LL2.3	LL2.3	0.14	0.73	0.54
Montcalm	LL2.3	LL.4	LL.4	0.79	0.99	0.99
Montcalm	LL.4	LL2.4	LL.3	0.88	0.75	0.84
Montcalm	LL.4	LL2.3	LL.4	0.45	0.64	0.55
Montcalm	LL2.4	LL.3	LL.3u	0.84	0.79	0.33
Saginaw	LL.3	LL.4	LL2.4	0.94	0.42	0.29

[a]Models were chosen using the *modelFit* function in R (Knezevic et al. 2007). LL.3, log logistic three-parameter model; LL.3u, log logistic three-parameter model with upper limit of 1; LL2.3, log logistic type 2 three-parameter model; LL2.3u, log logistic type 2 three-parameter model with upper limit of 1; LL.4, log logistic four-parameter model; LL2.4, log logistic type 2 four-parameter model; W1.3, Weibull three-parameter model; W1.4, Weibull four-parameter model; W2.3u, Weibull type 2 three-parameter model with upper limit of 1; W2.4, Weibull type 2 four-parameter model.

Table 3. Categorical variables associated with *Erigeron canadensis* accessions used in odds ratio analysis.

Accession location[a]	Phenotype[b]	Previous herbicide resistance[c]	Corn	Soybean	Winter wheat	Potato[d]	Pasture
			Frequency of crop in rotation (2015–2022)[e]				
Cass	G^R, D^{RS}, E^S	None	High	Low	Low	High	Low
Delta	G^S, D^S, E^S	Cloransulam	High	High	Low	Low	Low
Ingham	G^S, D^S, E^S	None	Medium	High	Low	Low	Low
Ingham	G^S, D^{RS}, E^{RS}	None	High	Medium	Low	Low	Low
Ingham	G^S, D^{RS}, E^S	None	High	High	Low	Low	Low
Ingham	G^R, D^{RS}, E^S	None	Low	Low	Low	Low	High
Ingham	G^S, D^S, E^S	None	Medium	Medium	Low	Low	Medium
Isabella	G^S, D^{RS}, E^S	None	Medium	High	Low	Low	Low
Isabella	G^S, D^S, E^{RS}	Cloransulam	Medium	High	Medium	Low	Low
Isabella	G^R, D^S, E^S	Cloransulam	Medium	High	Low	Low	Low
Macomb	G^R, D^{RS}, E^S	Cloransulam	Low	Low	Low	Low	High
Midland	G^R, D^S, E^S	Cloransulam	High	Low	Medium	Low	Low
Montcalm	G^S, D^S, E^S	Cloransulam	High	High	Low	Low	Low
Montcalm	G^R, D^{RS}, E^{RS}	Cloransulam	Medium	High	Low	Low	Low
Montcalm	G^R, D^{RS}, E^{RS}	Cloransulam	Medium	High	Medium	Low	Low
Montcalm	G^R, D^S, E^S	Cloransulam	Medium	High	Low	Low	Low
Montcalm	G^R, D^{RS}, E^S	Cloransulam	Low	High	Low	Low	Low
Montcalm	G^R, D^S, E^{RS}	Cloransulam	Medium	High	Low	Low	Low
Montcalm	G^R, D^{RS}, E^{RS}	Cloransulam	Medium	Low	Low	Low	High
Saginaw	G^R, D^S, E^S	Cloransulam	High	Medium	Low	Low	Low

[a]County accession collection within Michigan.
[b]Phenotyped through dose–response assays in objective 1 of this study; G, glyphosate; D, dicamba; E, 2,4-D; R, resistant; RS, reduced sensitivity; S, susceptible.
[c]Plant and Pest Diagnostics at Michigan State University previously evaluated these accessions for herbicide response (screened with 1× and 4× the recommended field use rate) to glyphosate, 2,4-D, dicamba, and cloransulam (Hill 2024).
[d]Potato (*Solanum tuberosum* L.).
[e]Crop rotation data were collected from USDA-NASS Cropland Data Layer using the CroplandCROS web application (USDA 2022). Once crop rotation information was extracted, the frequency of a particular crop grown in that rotation was calculated for each rotation and categorized as: high (greater than 50% of the years contained that crop), medium (20–50% of the years contained that crop), and low (less than 20% of the years contained that crop).

Powles 2009); however, it also led to successive selection events that in turn selected for widespread resistance in many troublesome weed species, including *E. canadensis* (Green 2007). Perhaps unsurprisingly then, we observed in our initial dose–response results that Michigan counties that are the largest producers of corn and soybean (Table 3) also have the highest level of glyphosate resistance (Table 1).

2,4-D and Dicamba

Out of the 20 accessions screened in our study, 7 (35%) had reduced sensitivity to 2,4-D (i.e., survived the recommended field use rate of 1.07 kg ae ha^{-1}) and 4 (20%) had reduced sensitivity to dicamba (i.e., survived the recommended field use rate of 0.56 kg ae ha^{-1}) (Table 1). These populations were considered as having "reduced

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

sensitivity" to 2,4-D and dicamba, as they survived the highest dose applied; however, as we did not apply a dose greater than the field use rate, it is unclear if they would be resistant in an agronomic setting. Overall, ED_{50} values for 2,4-D and dicamba varied widely across all 20 accessions, ranging between less than the lowest dose applied (<0.02 kg ae ha^{-1} and <0.01 kg ae ha^{-1} for 2,4-D and dicamba, respectively) to the recommended field use rate (>1.07 kg ae ha^{-1} and >0.56 kg ae ha^{-1} for 2,4-D and dicamba, respectively). Susceptible accessions for 2,4-D were found in all counties screened, except for Macomb and Cass, and in all counties for dicamba. Accessions with reduced sensitivity to 2,4-D were collected from Cass (one accession), Ingham (one accession), Isabella (one accession), Macomb (one accession), and Montcalm (three accessions) counties, while accessions with reduced sensitivity to dicamba were collected from Ingham (one accession), Isabella (one accession), and Montcalm (two accessions) counties.

To combat the rise in glyphosate resistance, agricultural companies have recently developed and released soybean varieties, Xtend/XtendFlex® and Enlist E3™, that are resistant to the auxinic herbicides dicamba and 2,4-D, respectively (Skelton et al. 2017). We screened our accessions of *E. canadensis* with 2,4-D and dicamba in an attempt to understand baseline sensitivity in this species in Michigan before these technologies are widely adopted. Our results show that in counties with high frequency of glyphosate-resistant *E. canadensis*, there is a corresponding decrease in auxinic herbicide sensitivity. Perhaps unsurprisingly, we see this pattern the most in Michigan counties that are the largest producers of corn and soybean (USDA-NASS 2024). For instance, 45% of all accessions with reduced sensitivity to auxin herbicides were collected from Montcalm County (Table 1), which is the 22nd producer of corn and 26th in soybean out of 83 counties in Michigan (USDA-NASS 2024). Auxin-mimicking herbicides have been extensively used in corn for a long time due to its natural tolerance; therefore, it is possible usage in corn started the selection process for auxinic resistance in *E. canadensis* that has the potential to be exacerbated by the future increased usage of auxinic herbicides in soybean.

Correlation

Overall, 30% of collected accessions are resistant or have reduced sensitivity to two or more of the herbicides tested. Among these multiple resistant populations, five are resistant to glyphosate and 2,4-D (Cass, Macomb, and Montcalm counties), two are resistant to glyphosate and dicamba (Montcalm county), and three have reduced sensitivity to both 2,4-D and dicamba (Ingham and Montcalm counties) (Table 1). Furthermore, two of collected accessions are resistant to all three herbicides assayed (Montcalm county) while five are susceptible to all three herbicides tested (Delta, Ingham, and Montcalm counties).

When ED_{50} values were compared among accessions treated with the auxinic herbicides 2,4-D and dicamba, Pearson's correlation coefficient was moderately positive, $r = 0.35$, indicating that increases in the ED_{50} for 2,4-D corresponds to increases in the ED_{50} value for dicamba (Figure 1). Furthermore, when ED_{50} values were compared among accessions treated with 2,4-D and glyphosate, Pearson's correlation coefficient was also moderately positive, $r = 0.21$, indicating glyphosate and 2,4-D resistance are positively correlated as well (Figure 1). Finally, when ED_{50} values were compared among accessions treated with dicamba and glyphosate, Pearson's correlation coefficient was weakly positive, $r = 0.15$ (Figure 1).

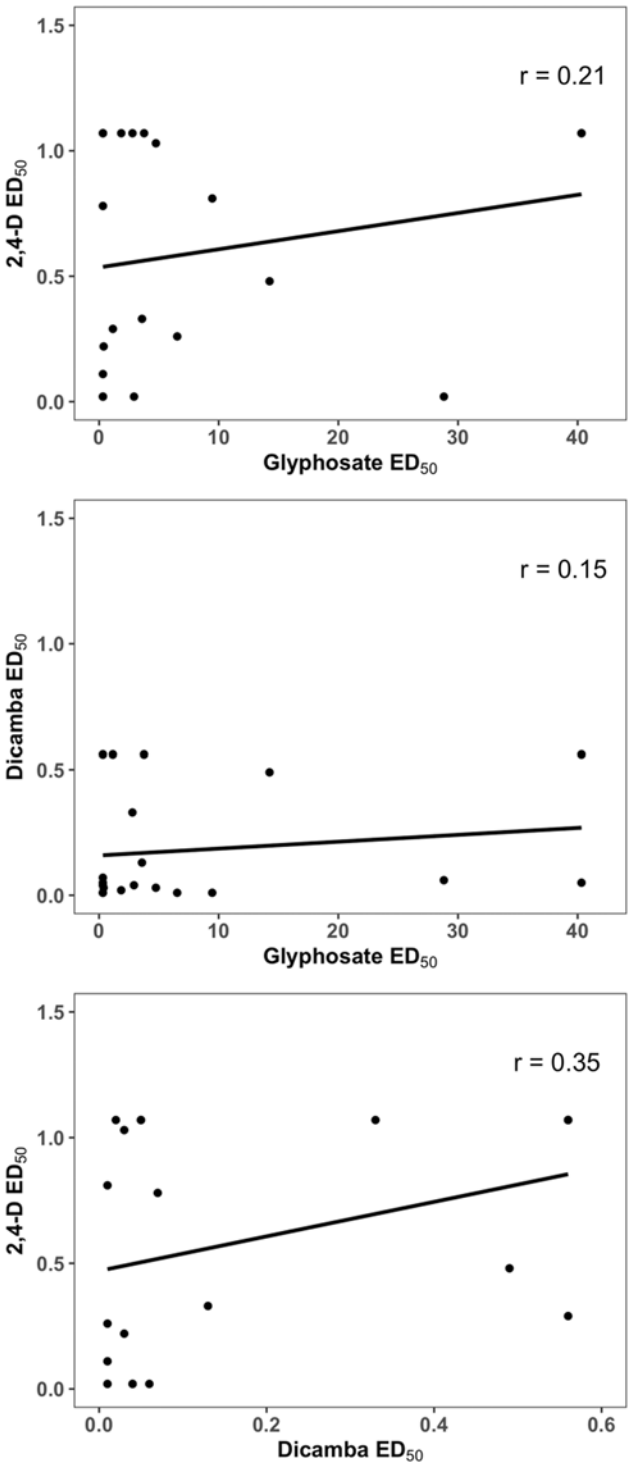

Figure 1. Pearson's correlation analysis between the mean herbicide dose (ED_{50} in kg ae ha^{-1}) required for 50% biomass reduction in 20 *Erigeron canadensis* accessions collected from eight counties in Michigan. ED_{50} values were calculated using dry plant biomass harvested 21 d after treatment using the DRC package in R. Field-recommended labeled rates are 1.26, 0.56, and 1.07 kg ae ha^{-1} for glyphosate, dicamba, and 2,4-D, respectively.

The moderately positive Pearson's correlation coefficient between dicamba and 2,4-D is interesting, as these herbicides are both Group 4 herbicides, but are from different chemical families and have been shown to have different protein binding partners, IAA16 and IAA2, respectively (LeClere et al. 2018;

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

Table 4. Results of odds ratio analysis of significant pairwise comparisons among categorical variables

General categorical variable	Comparison			Odds ratio	P-value
Previous herbicide resistance[a]	2,4-D RS	vs.	Glyphosate R	0.20	0.19
	Cloransulam R	vs.	Glyphosate R	0.15	0.08
	2,4-D RS	vs.	Dicamba RS	0.08	0.03
Location (counties in MI)[b]	Glyphosate R Montcalm	vs.	Glyphosate R Ingham	24.00	0.04
	Glyphosate R Montcalm	vs.	Glyphosate R Isabella	12.00	0.13
Crop rotation frequency[c]	Corn M	vs.	Dicamba RS	6.00	0.15
	Soybean L	vs.	2,4-D RS	5.60	0.17
	Soybean H	vs.	2,4-D RS	0.18	0.17
	Winter wheat L	vs.	Dicamba RS	0.15	0.17

[a]Plant and Pest Diagnostics at Michigan State University and dose–response assays in objective 1 of this study evaluated these accessions for herbicide response to glyphosate, 2,4-D, dicamba, and cloransulam (Hill 2024); R, resistant; RS, reduced sensitivity.
[b]County accession collection within Michigan.
[c]Crop rotation data were collected from USDA-NASS Cropland Data Layer using the CroplandCROS web application (USDA 2022). Once crop rotation information was extracted, the frequency of a particular crop grown in that rotation was calculated for each rotation and categorized as: high (H = greater than 50% of the years contained that crop), medium (M = 20–50% of the years contained that crop), and low (L = less than 20% of the years contained that crop).

Todd et al. 2020). Even though these herbicides are from different chemical families, a non–target site resistance (NTSR) mechanism(s) could be responsible for the moderate, but positive, correlation between these herbicides. Although not reported yet in *E. canadensis*, these NTSR mechanisms have been implied in cross-resistance for Group 4 herbicides in wild radish (*Raphanus raphanistrum* L.) (Goggin et al. 2016).

The moderate and weak correlation between glyphosate and 2,4-D and glyphosate and dicamba and glyphosate is notable. Regardless of strength, it is interesting to find a correlation between glyphosate and auxin-mimicking herbicides, as these herbicides are from different SOA and chemical families. Furthermore *E. canadensis* is a strongly self-pollinated species and thus lacks the ability to rapidly stack multiple resistance traits in a single individual or population, which is predicted in outcrossing species such as Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (Gaines et al. 2020; Powles 2008). These positive correlations are particularly concerning from a management perspective where growers will likely turn to Xtend/XtendFlex® and Enlist E3® technologies in an attempt to control glyphosate-resistant weeds, yet these populations seem primed to develop resistance to Group 4 herbicides already via previous exposure to Group 4 herbicides used in grass crops.

Odds Ratio

Previous Herbicide Resistance

Dose–response data were further analyzed using logistic regression to access the influence previous management history had on the occurrence of resistant accessions. Odds ratio analyses were performed using the ED_{50} values generated from the dose–response assays performed in objective 1 (Table 1), the previous herbicide-resistance screening performed at Plant and Pest Diagnostics at Michigan State University (Hill 2024), the county the accession was collected, and the crop rotation information from the location where the accession was collected using the USDA-NASS Cropland Data Layer CroplandCROS web application (USDA-NASS 2022) (Table 3). In total, 174 pairwise comparisons were performed for the analysis (Supplementary Table S2 in Supplementary File 2).

Among all combinations, nine were statistically meaningful (P-value < 0.20; Table 4) (Andrade 2019). Out of the significant pairwise comparisons, 33% involved comparisons of herbicide-resistance phenotypes identified in objective 1 to different SOAs previously screened (Hill 2024). First, if an *E. canadensis* accession has reduced sensitivity to 2,4-D, the odds the accession is glyphosate resistant increases by 20% (odds ratio [OR] = 0.20, P = 0.19; Table 4). Second, if an *E. canadensis* accession is resistant to cloransulam, the odds the accession is glyphosate-resistant increases by 15% (OR = 0.15, P = 0.08; Table 4). Finally, if an *E. canadensis* accession has reduced sensitivity to 2,4-D, the odds the accession has reduced sensitivity to dicamba increases by 8% (OR = 0.08, P = 0.03; Table 4).

Overall, our results suggest that resistance to one herbicide is associated with resistance to another in *E. canadensis*, a finding that is supported by previously published literature. In general, when one herbicide fails to control a weed, the primary alternative is to use a different herbicide chemical family or SOA to control those individuals, which can often lead to multiple herbicide resistance in which accessions are resistant to herbicides with different herbicide chemical families or SOAs (Beckie and Tardif 2012). Specifically, the co-occurrence of ALS and glyphosate resistance in *E. canadensis* has been reported by Byker et al. (2013). Furthermore, cross-resistance has occurred in wild mustard (*Sinapis arvensis* L.) to three auxin-mimicking herbicides from different chemical families (2,4-D, dicamba, and/or quinclorac) (Heap and Morrison 2002). Another case reported multiple resistance in Sumatran fleabane (*Erigeron. sumatrensis* Retz.) to paraquat, glyphosate, and chlorimuron (Albrecht et al. 2020). The results found in this study highlight the propensity of *E. canadensis* to evolve multiple resistance, especially in accessions that were already resistant to one SOA.

Location

The second most influential variable was location, for which combinations between the counties where the accessions were collected were analyzed to determine resistance. Specifically, glyphosate-resistant accessions were 2,400% (OR = 24.00, P = 0.04; Table 4) more likely to occur in Ingham County and 1,200% (OR = 12.00, P = 0.13; Table 4) more likely to occur in Isabella County when glyphosate resistance was already present in the neighboring county, Montcalm (Table 4; Figure 2). This is not surprising, as these counties have similar crop rotations—corn, soybean, and winter wheat—and thus share herbicide SOAs used in those rotations (USDA-NASS 2022). Interestingly, Isabella and Montcalm counties share a border, and because *E. canadensis* seed dispersal is wind mediated, the spread of resistance is potentially favored by the short distance between these counties.

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

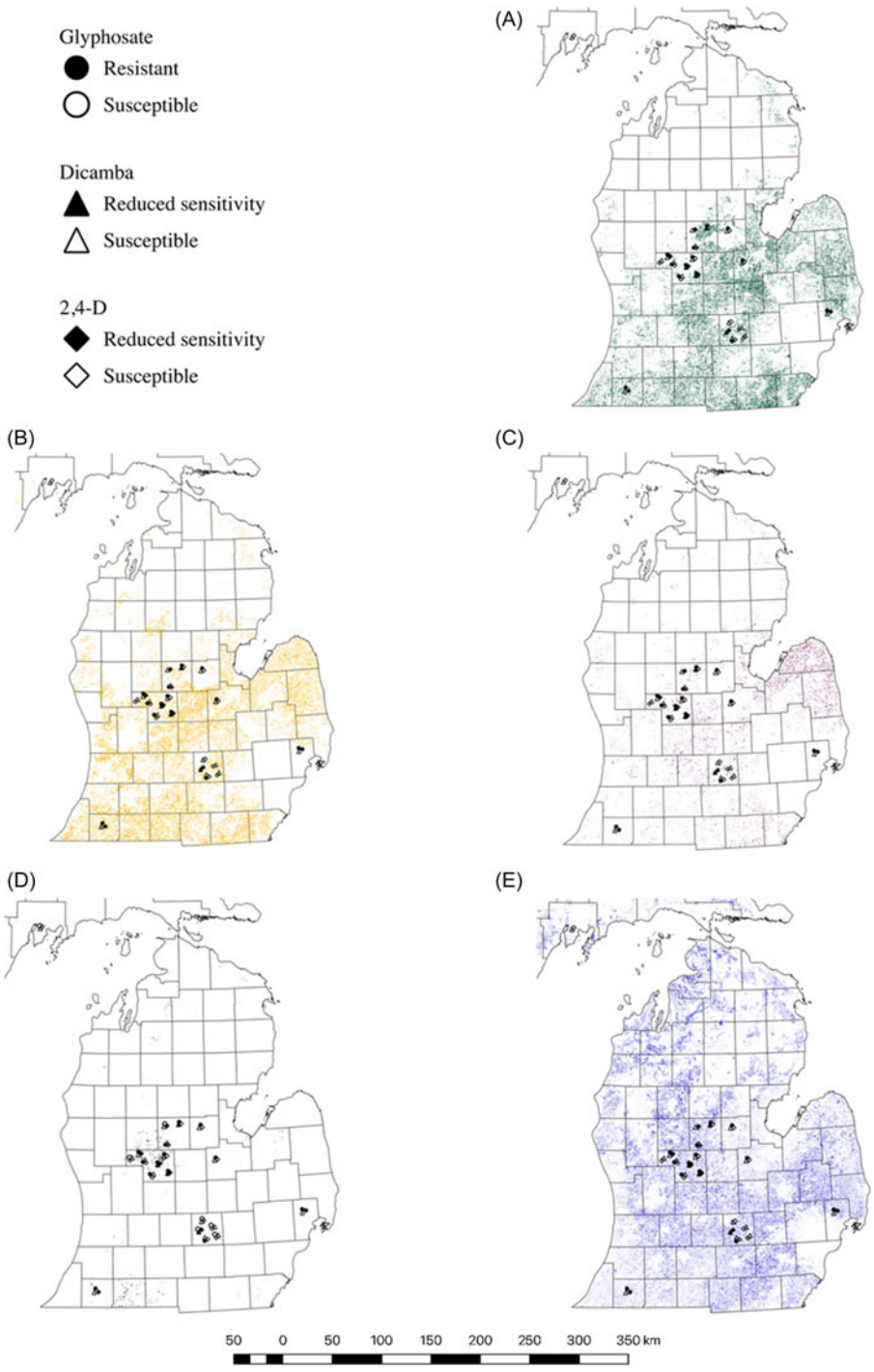

Figure 2. Location and resistance phenotype of *Erigeron canadensis* accessions that were collected throughout Michigan. Crop rotation data were collected from USDA-NASS Cropland Data Layer using the CroplandCROS web application from an 8-yr period (2015–2022; USDA 2022): (A) soybean, (B) corn, (C) winter wheat, (D) potatoes, and (E) and pasture.

Crop Rotation Frequency

The third most impactful variable was crop rotation frequency. When corn is planted between 20% to 50% of the years evaluated (medium frequency), the odds of *E. canadensis* having reduced dicamba sensitivity increases by 600% (OR = 6.00, P = 0.15; Table 4). When soybean is planted in <20% of the years evaluated (low frequency), the odds of *E. canadensis* having reduced 2,4-D sensitivity increases by 560% (OR = 5.60, P = 0.17; Table 4). When soybean is planted in >50% of the years (high frequency), the odds of *E. canadensis* having reduced 2,4-D sensitivity increases by 18% (OR = 0.18, P = 0.17; Table 4). Finally, when winter wheat is planted in <20% of years, the odds of *E. canadensis* having reduced dicamba sensitivity increases by 15% (OR = 0.15 P = 0.17; Table 4).

Crop rotation dictates what herbicide SOAs are used within a particular crop and across the rotation. With the introduction of auxin-resistant soybean varieties, there is potential that this SOA will be used more frequently or even continuously in the crop

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press

rotation, especially for soybean–corn rotations (Figure 2A and 2B). Furthermore, using the same herbicide SOA increases the selection pressure and speed at which *E. canadensis* evolves resistance to those SOAs (Evans et al. 2016). Specifically, the propensity of *E. canadensis* to evolve dicamba resistance increased in our study when corn was present at medium frequency in the rotation. Furthermore, our finding that having soybean represented at low frequency in the crop rotation leads to an increase in 2,4-D resistance is supported by the high frequency of grass crops (i.e., corn and pasture) as the main components of these low-soybean rotations (Table 3; Figure 2). Overall, these results suggest that having a medium to high frequency of grass crops, which are naturally tolerant to auxinic herbicides, in the rotation will predispose *E. canadensis* to have reduced sensitivity to auxinic herbicides when they are used more frequently in the future as adoption of auxin-resistant soybean increases. This is potentially already occurring, as our data indicated that there was a marginal increase in 2,4-D resistance in rotations with high frequency of soybean (Table 4).

The epidemiological approach utilized in this study begins to elucidate the main agronomic predictors of herbicide resistance in *E. canadensis* in Michigan. These predictors reiterate the importance of diverse management strategies and crop rotations to prevent future resistance evolution. The introduction of Group 4–resistant soybean does not enhance cropping system diversity, as these herbicides have already been used long term in corn and wheat phases of crop rotations. Alarmingly, we are already able to find *E. canadensis* accessions that have reduced sensitivity to 2,4-D and dicamba; therefore, it is possible that the introduction of Enlist™ and Xtend® technologies may only offer short-term relief and control of glyphosate-resistant weeds (Evans et al. 2016; LeClere et al. 2018; Todd et al. 2020) if used without other nonchemical management strategies. Not coincidentally, counties in the same agroclimatic zone are prone to have similar food production systems and therefore comparable overall management strategies and resistance issues (Evans et al. 2016).

Perhaps expectedly, similarity in food production and management strategies favors the evolution and spread of herbicide resistance in *E. canadensis*, highlighting that lack of diversity is a major factor in resistance evolution. Furthermore, in a wind-dispersed species such as *E. canadensis*, once herbicide resistance is established in a certain county, the proximity of counties potentially leads to the spread of herbicide-resistant accessions. The epidemiological approach performed in this study focused on evaluating a medium-sized dataset of categorical variables that are controllable by farmers. However, other drivers may be influencing the shift toward herbicide resistance of *E. canadensis* in Michigan, which will require more research to explore and integrate to form robust predictions. Overall, growers have the ability to *proactively* manage herbicide-resistance evolution progression of *E. canadensis* in Michigan by adopting integrated weed management (IWM) techniques to slow successive selection events that occur in low-diversity management systems. Specifically, IWM principles of crop rotation diversity and thus herbicide SOA diversity will enable farmers to diminish the threat of herbicide-resistance evolution in *E. canadensis* on their properties and in their regions.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/wsc.2025.6

Acknowledgments. A special thank you to Plant and Pest Diagnostics at Michigan State University for providing accessions for this study.

Funding statement. This work was supported by the Michigan Soybean Committee and Michigan State University Project GREEEN (Generating Research and Extension to meet Economic and Environmental Needs).

Competing interests. The authors declare no conflicts of interest.

References

Agostinetto D, Silva DRO da, Vargas L (2018) Soybean yield loss and economic thresholds due to glyphosate-resistant hairy fleabane interference. Arq Inst Biol 84, doi: 10.1590/1808-1657000022017

Albrecht AJP, Pereira VGC, Souza CNZ, Zobiole LHS, Albrecht LP, Adegas FS (2020) Multiple resistance of *Conyza sumatrensis* to three mechanisms of action of herbicides. Acta Sci Agron 42:1–9

Andrade C (2019) The P value and statistical significance: misunderstandings, explanations, challenges, and alternatives. Indian J Psychol Med 41:210–215

Beckie HJ, Tardif FJ (2012) Herbicide cross resistance in weeds. Crop Prot 35:15–28

Bhowmik PC, Bekech MM (1993) Horseweed (*Conyza canadensis*) seed production, emergence, and distribution in no-tillage and conventional-tillage corn (*Zea mays*). Agronomy 1:67–71

Byker HP, Soltani N, Robinson DE, Tardif FJ, Lawton MB, Sikkema PH (2013) Occurrence of glyphosate and cloransulam resistant Canada fleabane (*Conyza canadensis* L. Cronq.) in Ontario. Can J Plant Sci 93:851–855

Comont D, Hicks H, Crook L, Hull R, Cocciantelli E, Hadfield J, Childs D, Freckleton R, Neve P (2019) Evolutionary epidemiology predicts the emergence of glyphosate resistance in a major agricultural weed. New Phytol 223:1584–1594

Comont D, Neve P (2021) Adopting epidemiological approaches for herbicide resistance monitoring and management. Weed Res 61:81–87

Davis VM, Gibson KD, Johnson WG (2008) A field survey to determine distribution and frequency of glyphosate-resistant horseweed (*Conyza Canadensis*) in Indiana. Weed Technol 22:331–338

Davis VM, Kruger GR, Stachler JM, Loux MM, Johnson WG (2009) Growth and seed production of horseweed (*Conyza canadensis*) populations resistant to glyphosate, ALS-inhibiting, and multiple (glyphosate + ALS-inhibiting) herbicides. Weed Sci 57:494–504

Dodson L (2022) Adoption of Genetically Engineered Crops in the United States—Recent Trends in GE Adoption. U.S. Department of Agriculture–Economic Research Service. https://www.ers.usda.gov/Data-Products/Adoption-of-Genetically-Engineered-Crops-in-the-u-s/Recent-Trends-in-GE-Adoption. Accessed: July 1, 2024

Duke SO, Powles SB (2009) Glyphosate-resistant crops and weeds: now and in the future. AgBioForum 12:346–357

Evans JA, Tranel PJ, Hager AG, Schutte B, Wu C, Chatham LA, Davis AS (2016) Managing the evolution of herbicide resistance. Pest Manag Sci 72:74–80

Flessner ML, McElroy JS, McCurdy JD, Toombs JM, Wehtje GR, Burmester CH, Price AJ, Ducar JT (2015) Glyphosate-resistant horseweed (*Conyza canadensis*) control with dicamba in Alabama. Weed Technol 29:633–640

Ford L, Soltani N, Robinson DE, Nurse RE, McFadden A, Sikkema PH (2014) Canada fleabane (*Conyza canadensis*) control with preplant applied residual herbicides followed by 2,4-D choline/glyphosate DMA applied postemergence in corn. Can J Plant Sci 94:1231–1237

Gaines TA, Duke SO, Morran S, Rigon CAG, Tranel PJ, Küpper A, Dayan FE (2020) Mechanisms of evolved herbicide resistance. J Biol Chem 295: 10307–10330

Goggin DE, Cawthray GR, Powles SB (2016) 2,4-D resistance in wild radish: reduced herbicide translocation via inhibition of cellular transport. J Exp Bot 67:3223–3235

Green JM (2007) Review of glyphosate and ALS-inhibiting herbicide crop resistance and resistant weed management. Weed Technol 21:547–558

Hailpern SM, Visintainer PF (2003) Odds ratios and logistic regression: further examples of their use and interpretation. Stata J 3:213–225

Hallinan AJ (1993) A review of the Weibull distribution. J Qual Technol 25: 85–93

Harrell FE Jr (2015) Regression Modeling Strategies—With Applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis. 2nd ed. Cham, Switzerland: Springer. 582 p

Harrell FE Jr (2023) Hmisc: Harrell Miscellaneous. R Package Version 5.1-2. https://cran.r-project.org/web/packages/Hmisc/index.html. Accessed: September 18, 2023

Heap I (2014) Global perspective of herbicide-resistant weeds. Pest Manag Sci 70:1306–1315

Heap I (2023) The International Herbicide-Resistant Weed Database. www.weedscience.org. Accessed: September 26, 2023

Heap I, Morrison IN (2002) Resistance to auxin-type herbicides in wild mustard (*Sinapis arvensis* L.) populations in western Canada. Weed Sci Soc Am Abstr 55:32

Hill E (2024) History & Map of Herbicide-Resistant Weeds in Michigan. https://www.canr.msu.edu/pestid/resources/plant-and-weed-identification/map Accessed: June 7, 2024

Holm L, Doll J, Holm E, Pancho J, Herberger J (1997) World Weeds: Natural Histories and Distribution. New York: Wiley. 1129 p

Knezevic SZ, Streibig JC, Ritz C (2007) Utilizing R software package for dose-response studies: the concept and data analysis. Weed Technol 21:840–848

Koger CH, Poston DH, Hayes RM, Montgomery RF (2004) Glyphosate-resistant horseweed (*Conyza canadensis*) in Mississippi. Weed Technol 18:820–825

LeClere S, Wu C, Westra P, Sammons RD (2018) Cross-resistance to dicamba, 2,4-D, and fluroxypyr in *Kochia scoparia* is endowed by a mutation in an AUX/IAA gene. Proc Natl Acad Sci USA 115:E2911–E2920

Matzrafi M, Lazar TW, Sibony M, Rubin B (2015) *Conyza* species: distribution and evolution of multiple target-site herbicide resistances. Planta 242:259–267

Moretti ML, Bobadilla LK, Hanson BD (2021) Cross-resistance to diquat in glyphosate/paraquat-resistant hairy fleabane (*Conyza bonariensis*) and horseweed (*Conyza canadensis*) and confirmation of 2,4-D resistance in *Conyza bonariensis*. Weed Technol 35:554–559

Moretti ML, Hanson BD, Hembree KJ, Shrestha A (2013) Glyphosate resistance is more variable than paraquat resistance in a multiple-resistant hairy fleabane (*Conyza bonariensis*) population. Weed Sci 61:396–402

Moretti ML, Sosnoskie LM, Shrestha A, Wright SD, Hembree KJ, Jasieniuk M, Hanson BD (2016) Distribution of *Conyza* sp. in orchards of California and response to glyphosate and paraquat. Weed Sci 64:339–347

Muse AH, Mwalili SM, Ngesa O (2021) On the log-logistic distribution and its generalizations: a survey. Int J Stat Probab 10:93

Pearson K (1895) VII. Note on regression and inheritance in the case of two parents. Proc R Soc Lond 58:240–242

Powles SB (2008) Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Manag Sci 64:360–365

R Development Core Team (2021) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing

Ritz C, Baty F, Streibig JC, Gerhard D (2015) Dose-response analysis using R. PLoS ONE 10(12):e0146021

Schramski JA, Sprague CL, Patterson EL (2021) Environmental cues affecting horseweed (*Conyza canadensis*) growth types and their sensitivity to glyphosate. Weed Sci 69:412–421

Shields EJ, Dauer JT, VanGessel MJ, Neumann G (2006). Horseweed (*Conyza canadensis*) seed collected in the planetary boundary layer. Weed Sci 54:1063–1067

Skelton JJ, Simpson DM, Peterson MA, Riechers DE (2017) Biokinetic analysis and metabolic fate of 2,4-D in 2,4-D-resistant soybean (*Glycine max*). J Agric Food Chem 65:5847–5859

Soltani N, Shropshire C, Sikkema PH (2021) Control of glyphosate-resistant horseweed (*Conyza canadensis*) with tiafenacil mixes in corn. Weed Technol 35:908–911

Steckel LE, Gwathmey CO (2009) Glyphosate-resistant horseweed (*Conyza canadensis*) growth, seed production, and interference in cotton. Weed Sci 57:346–350

Todd OE, Figueiredo MR, Morran S, Soni N, Preston C, Kubeš MF, Napier R, Gaines TA (2020) Synthetic auxin herbicides: finding the lock and key to weed resistance. Plant Sci 300:110631

Trezzi MM, Balbinot AA Jr, Benin G, Debastiani F, Patel F, Miotto E Jr (2013) Competitive ability of soybean cultivars with horseweed (*Conyza bonariensis*). Planta Daninha 31:543–550

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2022) CroplandCROS. https://croplandcros.scinet.usda.gov. Accessed: May 19, 2023

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2023) Quick Stats: Agriculture across Michigan. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MICHIGAN. Accessed: July 7, 2023.

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2024) Michigan—County Estimates. https://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/County_Estimates/index.php. Accessed: June 1, 2024

VanGessel MJ (2001) Glyphosate-resistant horseweed from Delaware. Weed Sci 49:703–705

Van Wychen L (2024) Survey of the Most Common and Troublesome Weeds in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. https://wssa.net/wp-content/uploads/2024-survey-aquatic-noncrop.xlsx Accessed: June 1, 2024

Weaver SE (2001) The biology of Canadian weeds. 115. *Conyza canadensis*. Can J Plant Sci 81:867–875

https://doi.org/10.1017/wsc.2025.6 Published online by Cambridge University Press