Discovery of the first glyphosate-resistant grass weed in Canada

Lethbridge Research and Development Centre
Lethbridge, Alberta, Canada

Charles M. Geddes, and Mattea M. Pittman

Charles.Geddes@agr.gc.ca
@charlesmgeddes

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Canada

Introduction and Objectives

Downy brome (*Bromus tectorum* L.), otherwise known as cheatgrass, is a winter-annual, summer-annual, or occasionally biennial grass weed that was introduced to North America from Europe in the mid-1800s[1]. Since then, it spread throughout most of the continent resulting in significant infestations in cropland, pastureland and ruderal areas. In a 2017 mid-season survey of annual crops in Alberta, annual brome species [including downy brome and Japanese brome (*Bromus japonicus* Houtt.)] were most abundant in the Fescue Grassland, followed by the Moist Mixed Grassland and Mixed Grassland ecoregions[2]. Downy brome is problematic particularly in winter cereal crops grown in southern Alberta[3]. In the summer of 2021, an agronomist noted severe lack of control of a downy brome population in a glyphosate-resistant canola (*Brassica napus* L.) field in Taber County, Alberta, Canada, following four applications of glyphosate alone. The objectives of this research were to determine whether the putative glyphosate-resistant downy brome population (**a**) was glyphosate-resistant, (**b**) exhibited cross-resistance to other post-emergence (POST) herbicides, and (**c**) could be controlled by alternative POST herbicides.

Materials and Methods

Experiment 1: Greenhouse dose-response

- 2-way factorial RCBD
  - 10 glyphosate rates (Roundup WeatherMAX®; Bayer CropScience)
    - 0, 56, 112, 225, 450, 900, 1800, 3600, 7200, and 14400 g ae ha^{-1}
  - 3 downy brome populations
    - Putative resistant (R) (**Figure 1**)
    - Susceptible-1 (S-1)
    - Susceptible-2 (S-2)
- 15 downy brome plants pot^{-1} (10×10×12 cm)
- 4 replications, 2 experimental runs

Statistical analysis

- Nonlinear regression using the 'drc' package in R v. 3.6.0 (R Core Team 2019)
- Four-parameter log-logistic model:

$$y = c + \{d - c/1 + \exp[b(\log x - \log e)]\}$$

c = lower asymptote; d = upper asymptote; e = dose at the inflection point; y = response variable; x = glyphosate rate; b = slope at dose e

Experiment 2: Greenhouse POST herbicides

- 2-way factorial RCBD
  - 20 registered/unregistered POST herbicide treatments (**Table 1**) and untreated control
  - 2 downy brome populations
    - Putative resistant
    - Susceptible-1
- 10 downy brome plants pot^{-1} (12×12×15 cm)
- 4 replications, 2 experimental runs

Statistical analysis

- ANOVA using Proc MIXED in SAS Studio 3.81 (SAS Institute Inc., Cary, NC, USA)
- Fixed factors: Treatment and population
- Random factors: Replication nested within run
- Mean separation: Tukey's HSD (α = 0.05)

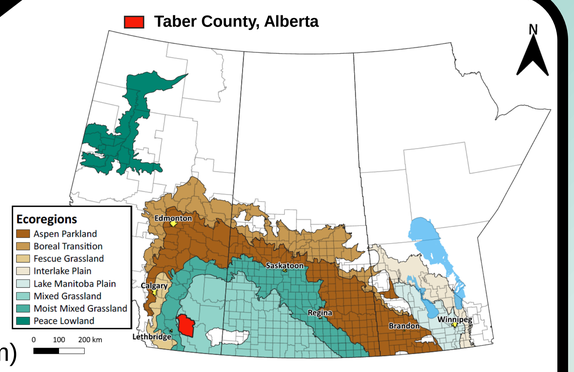

Figure 1. Map of the Canadian prairies showing the location of the putative glyphosate-resistant downy brome population.

Experimental procedures

- Herbicide applied at 2–3 leaf stage
  - Moving-nozzle cabinet sprayer
  - TeeJet® 8002VS flat fan nozzles
  - 275 kPa; 200 L ha^{-1} solution
- Response variables (3 wk after treatment)
  - Plant survival[4], visible control[5], biomass fresh weight (FW) and dry weight (DW)

Table 1. Post-emergence herbicide treatments evaluated.

Herbicide common name	Herbicide trade name	Rate (g ai/ae ha^{-1})
Glyphosate	Roundup WeatherMAX®[1]	900
Imazamox/Imazapyr	Ares™ SN[2]*	20/9
Quizalofop	Assure® II[3]†	48
Flucarbazone	Everest® 70 WDG[4]‡	24
Clethodim	Centurion®[5]§	45
Glufosinate	Liberty® 150 SN[5]§	500
Glufosinate + Clethodim	Liberty® 150 SN[5] + Centurion®[5]§	500 + 45
Imazamox + Bentazon + Quizalofop	MPower® Anaconda™[6]a¶†	20 + 430 + 48
Imazamox + Clethodim	MPower® Samurai® Master[6]b†	20 + 30
Pyroxsulam	Simplicity™[2]‡	11
Pyroxsulam	Simplicity™[2]‡	15
Imazamox	Solo® ADV[5]	20
Imazamox + Quizalofop	Solo® ADV[5] + Assure® II[3]	20 + 36
Imazamox/Bentazon	Viper® ADV[5]¶	20 + 430
Metribuzin	Squadron® II[7]	420
Metribuzin	Squadron® II[7]	560
Imazamox/Imazethapyr + Quizalofop	Odyssey® WDG[5] + Assure® II[3]†	15/15 + 36
Thiencarbazone	Varro™[1]‡	5
Tiafenacil	Tiafenacil[8]c††	50
Glufosinate + Tiafenacil	Liberty® 150 SN[5] + Tiafenacil[8]c††	500 + 50

Company names: [1] Bayer CropScience Inc.; [2] Corteva Agriscience Canada Company; [3] AMVAC Canada; [4] UPL AgroSolutions; [5] BASF Canada Inc.; [6] AgraCity Crop & Nutrition Ltd.; [7] ADAMA Agricultural Solutions Canada, Ltd.; [8] Gowan Canada.
Adjuvants: * Surjet 0.5% v/v; † Merge 0.5% v/v; ‡ Agral 90 0.25% v/v; § Amigo 0.5% v/v ; ¶ 28% UAN 1% v/v ; ** Merge 0.25% v/v ; †† MSO 1% v/v.
[a] Mixture of MPower Samurai® + MPower Boa® + MPower Quiz®
[b] Mixture of MPower Samurai® + MPower Independence®
[c] This product is currently being assessed for registration under the Pest Control Products Act.

Results and Discussion

- The putative resistant population exhibited **10.8- to 12.0-fold, 7.8- to 8.8-fold, 7.5- to 8.4-fold, and 7.7- to 8.4-fold resistance to glyphosate** based on plant survival, visible control, and biomass FW and DW 3 weeks after treatment, respectively, compared with the two susceptible populations (**Figures 2 & 3**). This confirmation of glyphosate-resistant downy brome in Alberta follows a 2020 report of a similar biotype in Washington, USA[6].
- The glyphosate rates that caused 50% plant mortality (**LD_{50}**), 50% visible control (**ED_{50}**), and 50% reduction in biomass FW and DW (**GR_{50}**) of the resistant population were **3029, 2106, 1740, and 1786 g ae ha^{-1}**, respectively (**Figures 2 & 3**). Therefore, typical field application rates of glyphosate in western Canada would not control this population. These LD_{50}, ED_{50}, and GR_{50} values were well above the glyphosate rates reported previously to control susceptible downy brome in this region[7].
- The glyphosate-resistant population **did not exhibit cross-resistance** to other POST herbicides (data not shown), corresponding with similar observations in Washington[8].
- **Quizalofop** alone or in combination with **imazamox**, **imazamox + bentazon**, or **imazamox/imazethapyr**, and **glufosinate** mixed with either **clethodim** or **tiafenacil** resulted in ≥ 80% visible control, plant mortality, and reduction in biomass DW of the glyphosate-resistant downy brome population (**Figures 4 & 5**). While downy brome is not known to exhibit resistance to other herbicides in Canada, resistance to a range of acetolactate synthase-inhibiting herbicides and clethodim was reported in Washington[8].

Results

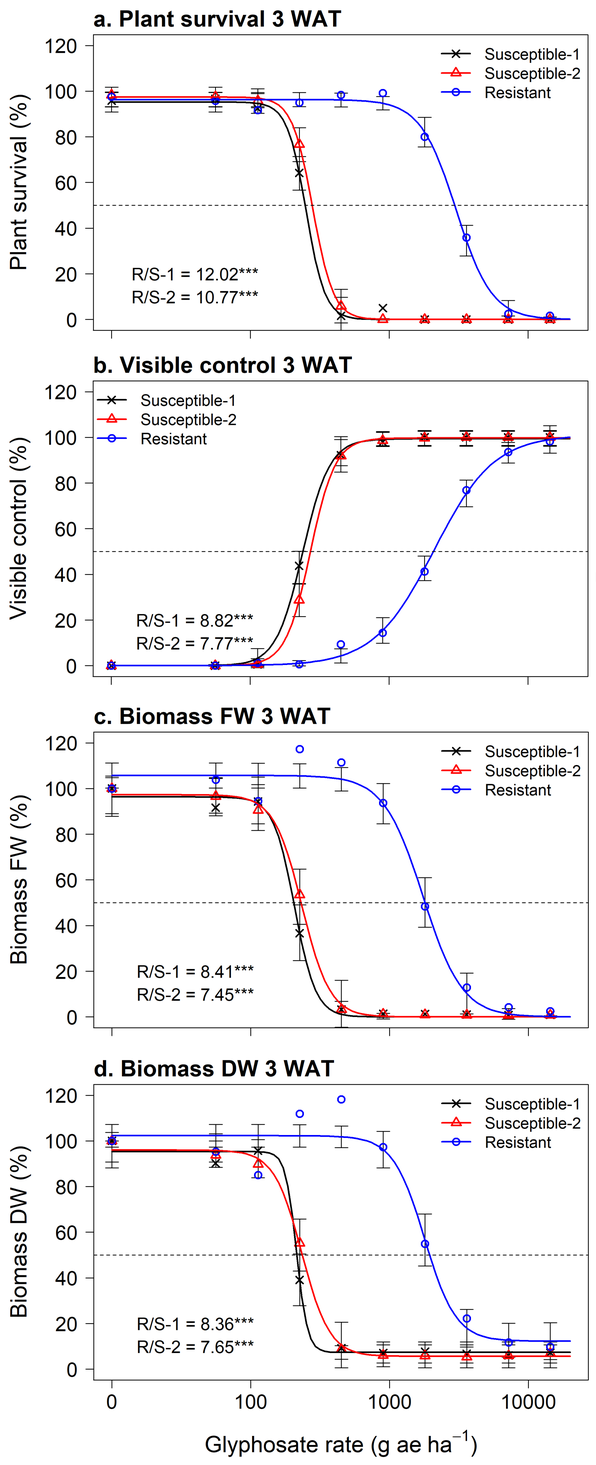

Figure 2. Plant survival (a), visible control (b), and biomass fresh weight (FW) (c), and dry weight (DW) (d) of three downy brome populations (Susceptible-1, Susceptible-2, and Resistant) three weeks after treatment (WAT) with ten rates of glyphosate in a combined analysis among experimental runs. Dots indicate means while error bars indicate ± SE. The dashed line indicates the 50% response level and R/S values indicate the resistance indices for the resistant population relative to each susceptible population.

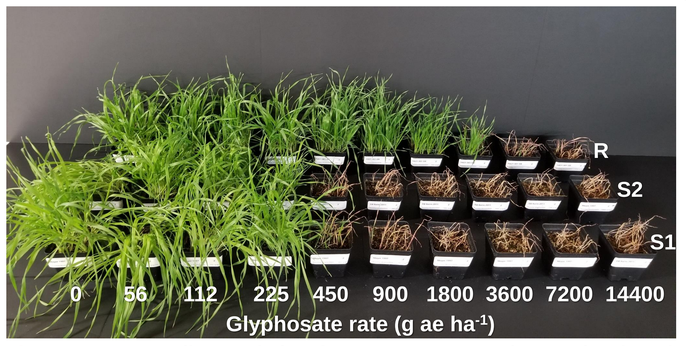

Figure 3. One replicate of the dose-response experiment showing the response of populations Susceptible-1 (S1; front), Susceptible-2 (S2; middle), and Resistant (R; back) to ten rates of glyphosate. Common field application rates in southern Alberta range between 450 and 900 g ae ha^{-1}.

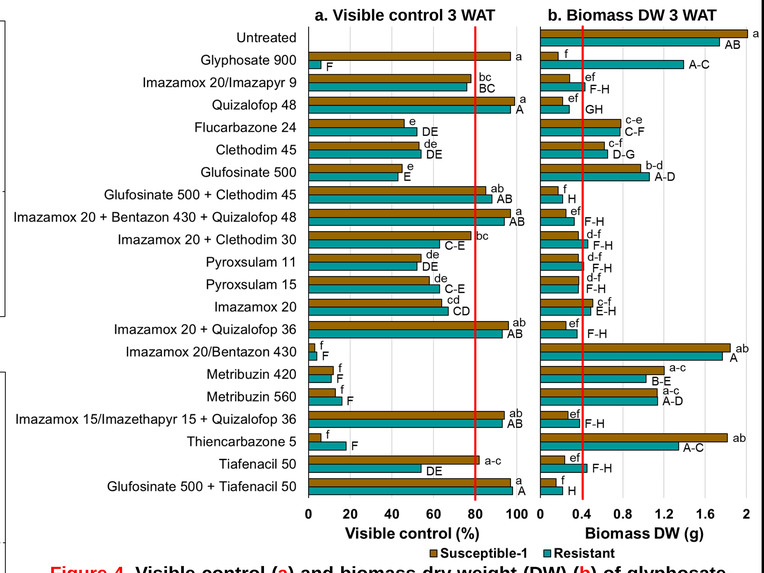

Figure 4. Visible control (a) and biomass dry weight (DW) (b) of glyphosate-resistant (Resistant) and -susceptible (Susceptible-1) downy brome 3 weeks after treatment (WAT) with a range of post-emergence herbicides and herbicide mixtures. Within subfigures and populations, different letters indicate significant difference based on Tukey's HSD (α = 0.05).

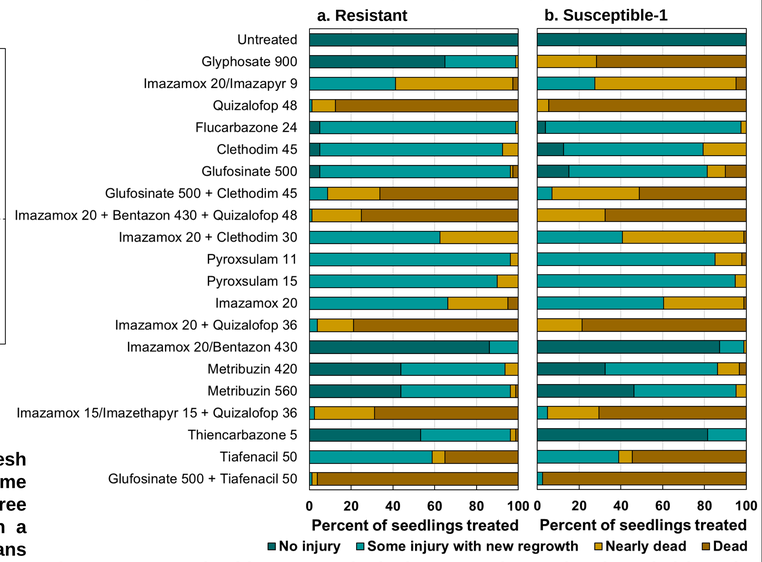

Figure 5. Mean health status of glyphosate-resistant (Resistant) (a) and glyphosate-susceptible (Susceptible-1) (b) downy brome plants 3 weeks after treatment with a range of post-emergence herbicides and herbicide mixtures.

Conclusions

The downy brome population was **confirmed glyphosate-resistant**, however, several alternative POST herbicides continue to control it effectively. This population represents the first known glyphosate-resistant grass weed in Canada.

Further research is warranted to determine the mechanism of glyphosate resistance in this downy brome population. A follow-up survey is planned for 2022 to elucidate the full scope of this problem in southern Alberta.

References

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[7] Blackshaw *et al.* 1991. *Weed Technol.* **5**:557-562
[8] Zuger and Burke. 2020. *Crops & Soils* **53**:13-19

Acknowledgments

Bayer CropScience | WGRF | Sask Wheat | Alberta Wheat Commission | Corteva agriscience | Manitoba Pulse & Soybean Growers | Manitoba | Manitoba Canola Growers | UPL | BASF We create chemistry | Gowan Canada | Government of Saskatchewan | Manitoba Crop Alliance | Agriculture and Agri-Food Canada | ADAMA | AgraCity