Wild oat herbicide resistance: Few active groups left

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Top 10 weeds in Alberta: 2010 survey (pre-harvest, 986 fields)

- 10: *Crepis tectorum* (narrow-leaved hawk’s-beard) ↑ (17th in 2001)
- 9: *Sonchus asper* (spiny annual sow thistle) ↑ (41st in 2001)
- 8: *Chenopodium album* (lambsquarters) ↓ (7th in 2001)
- 7: *Stellaria media* (chickweed) ↓ (3rd in 2001)
- 6: Volunteer canola ↑ (16th in 2001)
- 5: *Taraxacum officinale* (dandelion) ↑ (10th in 2001)
- 4: *Cirsium arvense* (Canada thistle) (no change)
- 3: *Galium spp.* (cleavers) ↑ (6th in 2001)
- 2: *Avena fatua* (wild oat) (no change)
- 1: *Polygonum convolvulus* (wild buckwheat) (no change)
Unique HR weed cases (biotypes) = 76
The rising incidence of HR weeds in western Canada

\[ M_{ha}/M_{ac} \]

- 2001 - 2003 surveys: 4.4 / 10.9
- 2007 - 2009 surveys: 9.9 / 24.4
2017 Alberta weed resistance (pre-harvest) survey

- 250 fields across Alberta
- Last survey in 2007
- Beckie, Shirriff, Leeson, Hall, Harker
- Funded ($240 K) by:
  - Western Grains Research Foundation
  - Alberta Wheat Commission
  - Alberta Pulse Growers Commission
  - Alberta Canola Producers Commission
2017 Alberta kochia / R. thistle post-harvest survey

Wheatland (36)
Foothills (15)
Vulcan (51)
Kneehill (9)
Starland (8)
Rocky View (8)
Lethbridge (27)
Cardston (18)
Pincher Creek (9)
Willow Creek (21)
Taber (18)
Acadia (5)
Cypress (21)
Forty Mile (39)
Warner (33)
Newell (12)
Total: 330 sites

• Beckie, Shirriff, Hall
• Funded by ACIDF
Wild Oat Resistance

Mechanisms of Resistance:

**Group 1 + 2:**
- Target-site mutations
- Enhanced metabolism

**Group 8:**
- Increased levels on endogenous gibberellin
- Enhanced metabolism
59% of fields where sampled; (32% in 2009, 10% in 2003)
Submissions to the CPL

![Graph showing submissions to the CPL from 2012 to 2016.](image)
Submissions to the CPL: by province
Gp 1-resistant wild oat

Submissions
2012-2016: 550 cases (AB=195)
32% of fields where sampled; (7% in 2009, 4% in 2003)
Submissions
2012-2016: 108 cases (AB=50)
25% of fields where sampled; (5% in 2009, 1% in 2003)
Gp 1- and 2-resistant wild oat

Submissions
2012-2016: 135 cases (AB=98)
## MB 2016 HR weed survey: grass weed resistance

<table>
<thead>
<tr>
<th>HR biotype</th>
<th># fields</th>
<th>total fields sampled</th>
<th>%</th>
<th># municipalities (74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gp 1 wild oat</td>
<td>79</td>
<td>101</td>
<td>78</td>
<td>51</td>
</tr>
<tr>
<td>Gp 2 wild oat</td>
<td>43</td>
<td>101</td>
<td>43</td>
<td>34</td>
</tr>
<tr>
<td>Gp 1+2 wild oat</td>
<td>42</td>
<td>101</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Gp 1 green foxtail</td>
<td>22</td>
<td>50</td>
<td>44</td>
<td>18</td>
</tr>
<tr>
<td>Gp 2 green foxtail</td>
<td>3</td>
<td>50</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Gp 1+2 green foxtail</td>
<td>1</td>
<td>50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Gp 1 yellow foxtail</td>
<td>19</td>
<td>60</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Gp 2 yellow foxtail</td>
<td>10</td>
<td>60</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Gp 1+2 yellow foxtail</td>
<td>4</td>
<td>60</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Gp 2 barnyard grass</td>
<td>3</td>
<td>11</td>
<td>27</td>
<td>3</td>
</tr>
</tbody>
</table>
## Multiple-resistant wild oat

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Wild oat herbicides</th>
<th>% Resistant Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Wheat</td>
<td>clodinafop</td>
<td>88</td>
</tr>
<tr>
<td>2005</td>
<td>Wheat</td>
<td>fenoxaprop</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>LL Canola</td>
<td>glufosinate/clethodim + clethodim</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Barley</td>
<td>pinoxaden + tralkoxydim</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Barley</td>
<td>imazamethabenz</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>RR Canola</td>
<td>glyphosate + glyphosate</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Wheat</td>
<td>triallate/trifluralin + clodinafop</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Field pea</td>
<td>ethalfluralin + quizalofop</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>Wheat</td>
<td>pyroxsulam</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>LL Canola</td>
<td>Glufosinate/clethodim</td>
<td></td>
</tr>
</tbody>
</table>
Wheat &/or barley herbicide options:
Gp 1+2-resistant wild oat

Altitude FX (FX2) (CL) — imazamox (2)
Assert — imazamethabenz (2)
Aurora — clodinafop (1)
Avadex — triallate (8) PRE
Avert — imazamethabenz (2)
Axial (iPak, Xtreme) — pinoxaden (1)
Bengal WB — fenoxaprop (1)
Bison — tralkoxydim (1)
Broadband — pinoxaden (1)
Bullwhip — clodinafop (1)
Cordon — fenoxaprop (1)
Cougar — fenoxaprop (1)
Everest 2.0 — flucarbazone (2)
HellCat — fenoxaprop (1)
Harmony Grass — clodinafop (1)
Ladder — clodinafop (1)
Foax — clodinafop (1)
Foothills NG — clodinafop (1)

Suppression:
Focus — pyroxasulfone (15) PRE
Trifluralin (3) PRE

Fortress MicroActiv — trifluralin (3), triallate (8) PRE
Inferno Duo — fluracarbazone (2)
Liquid achieve — tralkoxydim (1)
Marengo — tralkoxydim (1)
NextStep NG — clodinafop (1)
Nufarm Tralkoxydim Liquid — tralkoxydim (1)
Predicate — thiencarbazone (2)
Puma Advance — fenoxaprop (1)
Sierra 2.0 — flucarbazone (2)
Signal (FSU) — clodinafop (1)
Simplicity 30 OD (GoDRI) — pyroxsulam (2)
Slam’R — clodinafop (1)
Tandem — pyroxsulam (2)
Traxos (Two) — pinoxaden + clodinafop (1)
Tundra — fenoxaprop (1)
Varro — thiencarbazone (2)
Velocity m3 — thiencarbazone (2)
Vigil WB — fenoxaprop (1)
WildCat — fenoxaprop (1)
Multiple group-HR wild oat

- Resistance to groups 1 + 2 + 8 + 25
- Metabolic resistance

Symposium

Nature, Occurrence, and Cost of Herbicide-Resistant Wild Oat (Avena fatua) in Small-Grain Production Areas

HUGH J. BECKIE, A. GORDON THOMAS, ANNE LÉGÈRE, DAVID J. KELNER, RENE C. VAN ACKER, and SCOTT MEERS
Triallate-resistant wild oat (*Avena fatua* L.): unexpected resistance to pyroxasulfone and sulfentrazone

Amy R. Mangin, Linda M. Hall, and Hugh J. Beckie

Abstract: Wild oat is the most economically detrimental weed species in the Canadian Prairies and effective herbicidal control options are limited due to widespread resistance to ACCase inhibitors, ALS inhibitors, and lipid biosynthesis inhibitors; therefore, evaluation of new herbicidal modes of action such as pyroxasulfone and sulfentrazone for control is critical. Two wild oat populations (HR08-210 and HR11-151) were first subjected to a discriminating dose screen to characterize resistance to ACCase and ALS inhibiting herbicides in comparison with a susceptible population (S1988). Dose-response experiments with triallate, pyroxasulfone, and sulfentrazone were then conducted to evaluate potential cross-resistance. Screening indicated both herbicide-resistant (HR) populations were resistant to ACCase- and ALS inhibiting herbicides, most likely due to enhanced metabolism and an ACCase mutation. HR08-210 and HR11-151 were resistant to triallate (resistance ratios of 2.53 and 3.39, respectively), but cross-resistance to pyroxasulfone (2.78) and sulfentrazone (2.0) was only observed in HR11-151. Results indicate previously selected resistance to ACCase and ALS inhibitors (enhanced metabolism and ACCase mutation) or triallate (enhanced endogenous gibberellins) could limit the utility of new herbicide modes of action for control of wild oat.

Key words: cross-resistance, multiple resistance.

Résumé : La folle avoine est la mauvaise herbe économiquement la plus nuisible dans les Prairies canadiennes et les herbicides permettant de lutter contre elle sont peu nombreux en raison de la résistance très répandue aux inhibiteurs de ACCase, de VSP et de la biosynthèse de l’acide. Des essais de culture de population d’étude et d’essais de réponse en dose ont été effectués pour évaluer ça résistance à triallate, pyroxasulfone et sulfentrazone. Les cultures résistantes (HR) étaient résistantes à triallate (rapports de résistance de 2.53 et 3.39 respectivement) mais ne montraient que peu de résistance croisée à pyroxasulfone (2.78) et sulfentrazone (2.0). Les résultats suggèrent que la résistance précédemment sélectionnée à ACCase et ALS inhibiteurs (métabolisme amélioré et mutation ACCase) ou à triallate (endogènes gibberellins) pourrait limiter l’utilité des nouveaux modes d’action des herbicides pour le contrôle de folle avoine.
## Results: Dose-Response

Estimated LD$_{50}$ values and R/S ratios for wild oat populations S1988, HR08-210 and HR11-151 in a dose response study with triallate, pyroxasulfone and sulfentrazone

<table>
<thead>
<tr>
<th>Biotype</th>
<th>LD$_{50}$ (± SE)$^{z}$</th>
<th>R/S$^{y}$</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g ai ha$^{-1}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Triallate

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S1988</td>
<td>270 (50)</td>
<td>-</td>
<td>0.0088</td>
</tr>
<tr>
<td>HR08-210</td>
<td>681 (95)</td>
<td>2.53</td>
<td>0.0006</td>
</tr>
<tr>
<td>HR11-151</td>
<td>915 (81)</td>
<td>3.39</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

### Pyroxasulfone

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S1988</td>
<td>41 (8)</td>
<td>-</td>
<td>0.7429</td>
</tr>
<tr>
<td>HR08-210</td>
<td>46 (13)</td>
<td>1.13</td>
<td>0.7429</td>
</tr>
<tr>
<td>HR11-151</td>
<td>114 (13)</td>
<td>2.78</td>
<td>0.0063</td>
</tr>
</tbody>
</table>

### Sulfentrazone

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S1988</td>
<td>183 (13)</td>
<td>-</td>
<td>0.1740</td>
</tr>
<tr>
<td>HR08-210</td>
<td>236 (34)</td>
<td>1.28</td>
<td>0.1740</td>
</tr>
<tr>
<td>HR11-151</td>
<td>375 (83)</td>
<td>2.0</td>
<td>0.0290</td>
</tr>
</tbody>
</table>

$^{z}$LD$_{50}$, lethal dose to required for 50% survivorship of wild oat biotypes. The values in parentheses are standard errors.

$^{y}$R/S, ratio (resistant/susceptible) referred to the standard susceptible population S1988.
## Herbicide options in field pea

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Gp 1+2</th>
<th>Wild oat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clethodim (1)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sethoxydim (1)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Quizalofop (1)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sethoxydim +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imazethapyr/imazamox (1+2)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Imazethapyr/imazamox (2)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Imazethapyr (2)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Imazamox+bentazon (2+6)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ethafluralin (3; PRE)</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Trifluralin (3; PRE)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Triallate (8; PRE)</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
Top 10 HRWM practices

10: Maintaining a database: invaluable reference
9: Strategic tillage: if, where, or when needed
8: Field & site-specific weed mgmt: 1 size may not fit all
7: Weed sanitation:border control and slowing HR dispersal
6: In-crop wheat-selective herbicide rotation: combating NTSR
5: Herbicide gp rotation: avoid back-to-back in-crop gp 1 or 2
4: Herbicide mixtures/sequences: better than rotations
3: Pre- and post-herbicide scouting: know your enemy
2: Competitive crops & practices that promote competitiveness:
   natural biological control
1: Crop diversity
Top 10 weed management practices
2015 SK grower questionnaire (n = 600 respondents)

Scouting: before in-crop tmt
POST herbicide tmt
Herbicide tmts overall
Crop rotation
Scouting: before PRE tmt
Tank-mixing herbicides
Scouting: before fall tmt
Herbicide SOA rotation
PRE herbicide tmt
Scouting: after in-crop tmt
Top 10 weed management practices
2016 MB grower questionnaire (n = 108 respondents)
HRWM practices
2015 SK grower questionnaire (n = 250 respondents)

Overall, those with HR weeds rely more on herbicides at all application windows, and have greater adoption of:
• scouting before in-crop herbicide treatment
• tank-mixing herbicides
• herbicide SOA rotation
• growing weed-competitive crops
• increasing crop seeding rates vs. those without resistance
Overall, those with HR weeds rely more on herbicides at all application windows, and have greater adoption of:

- scouting before in-crop herbicide treatment
- tank-mixing herbicides
- herbicide SOA rotation
- growing weed-competitive crops
- tillage

vs. those without resistance
The cost of weed resistance in Saskatchewan: 2015

% of respondents (250)

No additional cost 7
$10/ac or less 41 ($24.70/ha or less)
$11 - $20/ac 23 ($49.40/ha)
$21 - $30/ac 11 ($74.10/ha)
$31 - $40/ac 6 ($98.80/ha)
$41 – 50 /ac 4 ($123.50/ha)
Unknown cost 8

Mean cost = $12 per acre or $30 per hectare
## The cost of weed resistance in Manitoba: 2016

### % of respondents (50)

<table>
<thead>
<tr>
<th>Cost Range</th>
<th>% Respondents</th>
<th>Mean Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No additional cost</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>$10/ac or less</td>
<td>56</td>
<td>($24.70/ha or less)</td>
</tr>
<tr>
<td>$11 - $20/ac</td>
<td>23</td>
<td>($49.40/ha)</td>
</tr>
<tr>
<td>$21 - $30/ac</td>
<td>9</td>
<td>($74.10/ha)</td>
</tr>
<tr>
<td>$31 - $40/ac</td>
<td>7</td>
<td>($98.80/ha)</td>
</tr>
<tr>
<td>$41 – 50/ac</td>
<td>0</td>
<td>($123.50/ha)</td>
</tr>
<tr>
<td>Unknown cost</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Mean cost = $11 per acre or $27 per hectare**
Annual crop area: 70 M ac

**Top 5 crops (M ac)**
- Canola: 22.9
- Wheat: 21.2
- Barley: 5.5
- Lentil: 4.4
- Field pea: 4.1

**Top 5 crops - AB (M ac)**
- Wheat: 7.1
- Canola: 6.9
- Barley: 2.8
- Field pea: 1.8
- Oats: 0.7

(SMF) (0.8)
HR canola in rotation:
- ca. ½ RR; ½ LL
(2012-2014 crop years)

- (220 respondents) %
- Canola 1 in 2 yr 46
- Canola 1 in 3 yr 23
- Canola 1 in 4 yr or less 17
- Continuous canola 4
- No canola 10

Net return: $/ac (2017):
Wheat: 95
Canola: 178
Barley (malt): 69
Lentil: 275
Field pea: 103
16-ha (347.2 x 445 m) experiment, Scott, SK since 1995
### Nine alternative cropping systems

<table>
<thead>
<tr>
<th>Input level</th>
<th>Diversity level</th>
<th>Crop sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>DAG</td>
<td>Can-rye-pea-bar-flx-whe</td>
</tr>
<tr>
<td></td>
<td>DAP</td>
<td>Bar-alf-alf-alf-can-whe</td>
</tr>
<tr>
<td></td>
<td>LOW</td>
<td>TF-can-whe-TF-whe-whe</td>
</tr>
<tr>
<td>RED</td>
<td>DAG</td>
<td>Can-rye-pea-bar-flx-whe</td>
</tr>
<tr>
<td></td>
<td>DAP</td>
<td>Bar-alf-alf-alf-can-whe</td>
</tr>
<tr>
<td></td>
<td>LOW</td>
<td>CF-can-whe-GM-whe-whe</td>
</tr>
<tr>
<td>ORG</td>
<td>DAG</td>
<td>GM-whe-pea-bar-GM-mus</td>
</tr>
<tr>
<td></td>
<td>DAP</td>
<td>Bar-alf-alf-mus-whe</td>
</tr>
<tr>
<td></td>
<td>LOW</td>
<td>GM-mus-whe-GM-whe-whe</td>
</tr>
</tbody>
</table>
# Gp 1-resistant wild oat population frequency

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Gp 1 appl. (no.)</th>
<th>WO panicles (no. m⁻²)</th>
<th>WO resistance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH-DAG</td>
<td>10</td>
<td>6.8 c</td>
<td>42.3 b</td>
</tr>
<tr>
<td>HIGH-DAP</td>
<td>6</td>
<td>0.7 d</td>
<td>2.7 d</td>
</tr>
<tr>
<td>HIGH-LOW</td>
<td>4</td>
<td>13.4 b</td>
<td>12.3 c</td>
</tr>
<tr>
<td>RED-DAG</td>
<td>7</td>
<td>7.4 c</td>
<td>60.0 a</td>
</tr>
<tr>
<td>RED-DAP</td>
<td>4</td>
<td>2.8 d</td>
<td>0 d</td>
</tr>
<tr>
<td>RED-LOW</td>
<td>5</td>
<td>18.0 a</td>
<td>14.9 c</td>
</tr>
<tr>
<td>ORG-LOW</td>
<td>0</td>
<td>11.1 b</td>
<td>0 d</td>
</tr>
</tbody>
</table>

*a-d: LSD test*
Site-specific weed management
Nontreated

1997

1997

2002

Treated

Patch Management of Herbicide-Resistant Wild Oat (*Avena fatua*)

Hugh J. Beckie, Linda M. Hall, and Barclay Schuba
Panicle Clipping
Wild oat biomass at maturity

Seed rate: 200 to 400/m² = 3X reduction
Cultivar: short to tall = 2X reduction
Both factors = 8X reduction
All factors = 70X reduction

(Harker et al.)
Wild oat seed production

1x to 2x seeding rate = 4X reduction
Short to Tall cultivar = 2X reduction
Both factors = 10X reduction
All 3 factors = 37X reduction
Evaluating Seed Shatter of Economically Important Weed Species

Nikki R. Burton, Hugh J. Beckie, Christian J. Willenborg, Steven J. Shirtliffe, Jeff J. Schoenau, and Eric N. Johnson*

The increasing occurrence of herbicide resist developed in over 30 yr, have increased the tactics. Harvest weed seed control (HWSC) p manage problematic weeds. For HWSC to b retained on the plant at crop maturity. This 2 oat, green foxtail, wild mustard, and cleavers. Maturity crop in field experiments at Scott: trays collected once a week during crop ripen stages (swathing, direct-combining). Seed sh: between crops at maturity: ca. 30% for wild oat for green foxtail. Overall, seed shatter of wild oats is lower compared to other weeds.

Factors Affecting Weed Seed Devitalization with the Harrington Seed Destructor

Breanne D. Tidemann, Linda M. Hall, K. Neil Harker, and Hugh J. Beckie*

The Harrington Seed Destructor (HSD), a novel weed control technology, has been highly effective in field-based research studies. Factors affecting seed devitalization efficiency are critical for the HSD's success in reducing weed seed banks.
Conclusions

• Continual weed resistance surveillance via field surveys and submission sample testing is a continuing high priority
• Present and future weeds (?) with glyphosate resistance is and will be an important focal point of research
• BUT…. overall, wild oat (multiple) resistance will continue to be the #1 HR weed problem across western Canada
• Consistent application of BMPs is the best long-term strategy (tortoise vs. hare fable)
• W. Canada producers are now using a number of these BMPs – but we need new tools soon!