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SHORT COMMUNICATION

Triple-resistant kochia [*Kochia scoparia* (L.) Schrad.] in Alberta

Hugh J. Beckie, Linda M. Hall, Scott W. Shirriff, Elise Martin, and Julia Y. Leeson

Abstract: A randomized stratified survey was conducted in Alberta in 2017 to determine the distribution and abundance of multiple-resistant (acetolactate synthase (ALS) inhibitor, glycine, synthetic auxin) kochia. All populations were ALS inhibitor-resistant, with glyphosate and dicamba resistance confirmed in 50 and 18% of populations, respectively. Ten percent of populations exhibited resistance to all three site-of-action herbicides.

Key words: auxinic resistance, glyphosate resistance, herbicide resistance, kochia, multiple resistance, survey.

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Introduction

A baseline survey conducted across southern Alberta in 2012 documented the distribution and abundance of glyphosate-resistant (GR) kochia [*Kochia scoparia* (L.) Schrad.] (Hall et al. 2014). This survey followed the first confirmation of GR kochia in Canada in three chem-fallow fields in Alberta (Warner county) in 2011 (Beckie et al. 2013). Four years previously, GR kochia had been reported in Kansas, United States (U.S.); it is now listed as occurring in 10 states (Heap 2018). The randomized stratified survey in Alberta comprised kochia populations from 309 sites (field or ruderal areas) across 12 counties/municipal districts (MDs). Resistance screening indicated 13 GR kochia populations (ca. 5%): seven in Warner county (fields), five in Vulcan county (three fields, ditch, railway right-of-way), and one in Taber county (field). Most surveyed fields were chem-fallow. All GR populations were resistant to acetolactate synthase (ALS) inhibitors. Today, all prairie kochia populations are assumed to be ALS inhibitor-resistant, as confirmed by random testing. Similar baseline surveys in 2013 in Saskatchewan and Manitoba found 17 (5%) and 2 (< 1%) GR populations, respectively (Beckie et al. 2015).

The recent introduction of GR and dicamba-resistant (DR) soybean cultivars has renewed interest in the occurrence of synthetic auxin resistance in weeds. With the evolution of GR kochia across western Canada, their successful management is contingent on alternative herbicide sites-of-action, principally synthetic auxins (Group 4). However, an auxin (plus ALS inhibitor)-resistant kochia population was discovered in a wheat field in southern Saskatchewan in 2015 (H. Beckie, unpublished data). Dose-response experiments confirmed that the population was resistant to dicamba and fluroxypyr. This discovery as well as previous reports of auxinic-resistant kochia in six U.S. states (first report in Montana in 1994; Heap 2018), necessitated the monitoring of auxin resistance in this weed in future western Canadian surveys. Accordingly, a

second survey was conducted in Alberta in 2017, five years after the 2012 baseline survey, to determine the distribution and abundance of multiple-resistant (acetolactate synthase inhibitor, glycine, synthetic auxin) kochia.

Materials and Methods

A survey of multiple-resistant kochia was conducted post-harvest in fall, 2017. Similar to the 2012 Alberta survey, a randomized stratified design was used to select sites (Hall et al. 2014). The number of survey sites was stratified, proportional to cultivated land area per ecodistrict (geographic area within an ecoregion similar in landform, soil, vegetation, and land use) within the Southern Alberta agricultural extension region, covering four agricultural ecoregions (Agriculture and Agri-Food Canada 2003). Surveyors drove to 305 randomly predetermined sites (township scale) across 16 counties/MDs during the 3-wk post-harvest survey period in September and October, 2017. Approximately 10 to 20 mature kochia plants were randomly collected at each site, and placed in a paper bag to form a composite sample. A survey form was completed on-site for each population, and a photograph taken with global positioning system (GPS) reference. Populations were sampled in fields, and ruderal areas such as roadsides/ditches, railway rights-of-way, and oil well sites.

Samples were threshed under contained conditions at the University of Alberta in Edmonton, and seed samples screened for herbicide resistance at Saskatoon, SK from January to September of 2018. From each population, seeds were planted in 52-cm by 26-cm by 5-cm flats containing potting soil. A minimum of 100 seedlings per population (three flats or replicates per experiment run and repeated) were sprayed with glyphosate (Roundup WeatherMax, 540 g a.e. L⁻¹), tribenuron/thifensulfuron (Refine SG, 16.6% tribenuron, 33.3% thifensulfuron), or dicamba

(Banvel II, 480 g a.i. L⁻¹) at discriminating doses of 900 g a.e. ha⁻¹, 15 (5 + 10) g a.i. ha⁻¹, and 280 g a.i. ha⁻¹, respectively, when seedlings were 3 to 5 cm tall (Beckie et al. 2015). Herbicides were applied using a moving-nozzle cabinet sprayer equipped with a flat-fan nozzle tip (TeeJet 8002VS, Spraying Systems Co., Wheaton, IL, USA) calibrated to deliver 200 L ha⁻¹ of spray solution at 275 kPa. Three weeks after treatment, plant response to herbicide application was visually scored as susceptible (dead or nearly dead) or resistant (some injury but new growth, or no injury). Assessments were made relative to herbicide-treated and -untreated susceptible and resistant check populations (Beckie et al. 2015). The DR check population originated from Saskatchewan. The percentage or frequency of herbicide-resistant individuals in a population was calculated as the number of seedlings rated as resistant divided by the total number screened, multiplied by 100.

Results and Discussion

All kochia populations were categorized as resistant to the ALS inhibitor tribenuron/thifensulfuron, similar to results of previous kochia surveys in 2012 and 2013 (Hall et al. 2014; Beckie et al. 2015). GR kochia was confirmed in 15 of 16 counties/MDs (Fig. 1), compared with only three counties/MDs in 2012. GR kochia was not found in Kneehill county. Of the 305 populations tested, glyphosate only (i.e., dicamba resistance negative) resistance was confirmed in 122 of them (40%). Most populations were observed to be segregating for resistance, with an average of 38% of individuals in a population classified as GR. GR kochia was found at 12 oil well sites, 12 ditch areas, with the remaining sites (98) within annually-cropped fields. In contrast to the 2012 survey, GR kochia was not strongly associated with chem-fallow (< 20% of fields). Instead, GR kochia was found in small-grain cereals (37%), oilseeds (canola, flax,

mustard) (14%), pulses (lentil, field pea) (19%), and large-grain cereals (corn) (11%). The eight corn fields with GR kochia were located throughout Newell county.

DR only (i.e., glyphosate resistance negative) kochia was found in 24 of the 305 populations (8%) in six counties/MDs (Fig. 1). In contrast, all populations screened with dicamba in the 2012 survey were susceptible. DR kochia was found at one oil well site, four ditch areas, and 19 fields (two-thirds cereals, one-quarter pulses, with remainder oilseeds). Similar to glyphosate resistance, populations were segregating for dicamba resistance, with an average of 14% of individuals in a population classified as DR. This low frequency is consistent with early stages of resistance evolution in populations across the southern prairie region.

Triple-resistant kochia (ALS+GR+DR) was found in 31 of the 305 populations (10%) in nine counties/MDs as well as Special Area 3 (Fig. 1). Therefore, GR and DR kochia comprises a total of 50 and 18% of populations sampled, respectively. When one considers that GR kochia was confirmed in only 5% of populations and restricted to three counties/MDs in the previous survey in 2012 (Hall et al. 2014), the incidence of glyphosate resistance in this weed in 2017 is alarming. The biotype now infests virtually all jurisdictions in southern Alberta where kochia occurs. However, it should not be surprising that the rapidity of glyphosate resistance evolution would parallel that of ALS inhibitor resistance given the tremendous magnitude of gene flow of herbicide resistance alleles (Beckie et al. 2016). We expect GR kochia to comprise over two-thirds of populations when surveyed within the next 5 years. We also expect a similar trend of GR kochia evolution to occur in Saskatchewan in the planned 2019 survey.

Prior to this survey, the only reported case of auxinic-resistant kochia in western Canada was a population in a wheat field in southern Saskatchewan in 2015. The population exhibited low-level resistance to both dicamba and fluroxypyr. Further testing of these Alberta DR

populations with fluroxypyr and other auxinic herbicides will help elucidate the prevailing cross-resistance pattern. All triple-resistant populations, except one (ditch area), were found within fields (50% cereals, 15% oilseeds, 15% pulses, 20% chem-fallow). The average frequency of GR and DR individuals in the populations were 34 and 17%, respectively. In the U.S., this triple-resistant biotype (also photosystem-II inhibitor) was reported in Kansas in 2013 (Varanasi et al. 2015).

It appears that auxinic resistance evolution in kochia will follow the same scenario as that of ALS inhibitor and glyphosate resistance – tragedy of the commons. In a regional study conducted across western Canada, it was concluded that GR kochia populations with high or low enolpyruvylshikimate-3-phosphate synthase (EPSPS) copy number showed little genetic differentiation (no correlation between genetic and geographic distance, i.e., high connectivity) and maintained similar genetic diversity as a result of high gene flow (S. Martin et al., unpublished data). The authors concluded that any herbicide resistance alleles will be able to spread quickly through the entire population and that the spread of these alleles appears unlikely to reduce the genetic variation of these populations. Frequent and widespread applications of glyphosate and auxinic herbicides across the Canadian prairies provides connective high-fitness habitats across the landscape. When combined with the tremendous magnitude of recurrent, unrelenting gene flow of herbicide resistance alleles, the inevitable result is frequent, widespread multiple-resistant trait stacking in individuals and populations (Dauer et al. 2009).

Growers have relied upon auxinic herbicides to manage GR kochia. Preseeding or chem-fallow herbicide options to control triple-resistant kochia rely upon protoporphyrinogen oxidase (PPO) inhibitors (Group 14) (Table 1). Other preseeding herbicide sites-of-action include ethalfluralin (Group 3), bromoxynil (Group 6), and pyroxasulfone (Group 15). In-crop herbicide

options include bromoxynil in cereals and flax, glufosinate (Group 10) in glufosinate-resistant canola, soybean, or corn, bromoxynil+pyrasulfotole (Group 27) in wheat and barley, and topramezone (Group 27) in corn. There are no in-crop herbicide options in mustard, field pea, or lentil. Inevitably, greater utilization of non-herbicidal weed management practices will be required to minimize crop seed yield and quality loss (Beckie and Harker 2017). In particular, weed sanitation (minimizing gene flow immigration into fields, harvest weed seed control, etc.) is important to manage multiple-resistant kochia, which has become one of the most abundant and troublesome herbicide-resistant weeds in the southern prairies. The weakness in its life cycle is the short seed bank longevity (<1 yr), which can be exploited to reduce population abundance if weed management can mitigate seed return (Beckie et al. 2018).

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References

- Agriculture and Agri-Food Canada. 2003. A national ecological framework for Canada: GIS data. [Online] Available from http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html.
- Anonymous. 2018. 2018 Guide to crop protection. Saskatchewan Ministry of Agriculture, Regina, SK [Online] Available from <http://www.publications.gov.sk.ca/details.cfm?p=77706>.
- Beckie, H.J. and Harker, K.N. 2017. Our top 10 resistant weed management practices. *Pest Manag. Sci.* **73**: 1045–1052.
- Beckie, H.J., Blackshaw, R.E., Hall, L.M., and Johnson, E.N. 2016. Pollen- and seed-mediated gene flow in kochia (*Kochia scoparia*). *Weed Sci.* **64**: 624–633.
- Beckie, H.J., Blackshaw, R.E., Leeson, J.Y., Stahlman, P.W., Gaines, T.A., and Johnson, E.N. 2018. Seedbank persistence, germination and early growth of glyphosate-resistant *Kochia scoparia*. *Weed Res.* **58**: 177–187.
- Beckie, H.J., Blackshaw, R.E., Low, R., Hall, L.M., Sauder, C.A., Martin, S., Brandt, R.N., and Shirriff, S.W. 2013. Glyphosate- and acetolactate synthase inhibitor-resistant kochia (*Kochia scoparia*) in western Canada. *Weed Sci.* **61**: 310–318.
- Beckie, H.J., Gulden, R.H., Shaikh, N., Johnson, E.N., Willenborg, C.J., Brenzil, C.A., Shirriff, S.W., Lozinski, C., and Ford, G. 2015. Glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in Saskatchewan and Manitoba. *Can. J. Plant Sci.* **95**: 345–349.
- Dauer, J.T., Luschei, E.C., and Mortensen, D.A. 2009. Effects of landscape composition on spread of an herbicide-resistant weed. *Landscape Ecol.* **24**: 735–747.
- Hall, L.M., Beckie, H.J., Low, R., Shirriff, S.W., Blackshaw, R.E., Kimmel, N., and Neeser, C. 2014. Survey of glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in Alberta. *Can. J.*

Plant Sci. **94**: 127–130.

Heap, I.M. 2018. International survey of herbicide resistant weeds [Online] Available from <http://www.weedscience.org>.

Varanasi, V.K, Godar, A.S., Currie, R.S., Dille, A.J., Thompson, C.R., Stahlman, P.W., and Jugulam, M. 2015. Field-evolved resistance to four modes of action of herbicides in a single kochia (*Kochia scoparia* L. Schrad.) population. Pest Manag. Sci. **71**: 1207–1212.

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Table 1. Herbicides (group number in parenthesis) to control kochia resistant to ALS inhibitors, dicamba, and glyphosate (Groups 2+4+9, respectively) at preseeding, in-crop (10 selected field crops), and chem-fallow in western Canada (Anonymous 2018).^a

	Wheat	Barley	Oat	Corn	Canola	Mustard	Flax	Soybean	Pea	Lentil
<u>Preseeding</u>										
Ethalfluralin (3)					X	X		X	X	X
Bromoxynil (6)	X	X	X		X					
Carfentrazone (14)	X	X	X	X	X	X	X	X	X	X
Saflufenacil (14)	X	X	X	X				X	X	X
Sulfentrazone (14)						X	X	X	X	
Flumioxazin (14)	X							X	X	X
Sulfentrazone+ pyroxasulfone (14,15)								X	X	
Flumioxazin+ pyroxasulfone (14,15)	X							X		
<u>In-crop</u>										
Bromoxynil (6)	X	X	X	X			X			
Glufosinate (10) ^b				X	X					
Topramezone (27)				X						
Bromoxynil+ pyrasulfotole (6,27)	X	X								
<u>Chem-fallow</u>										
Carfentrazone (14)										
Saflufenacil (14)										
Flumioxazin (14)										
Flumioxazin+ pyroxasulfone (14,15)										

^aFollow Anonymous (2018) if any discrepancy.^bLiberty Link varieties only.

Figure Captions

Fig. 1. Double-resistant: ALS inhibitor+glyphosate (ALSR+GR); ALS inhibitor+dicamba (ALSR+DR) and triple-resistant: ALS inhibitor+glyphosate+dicamba (ALSR+GR+DR) kochia in southern Alberta in 2017.

Fig. 2. Triple-resistant kochia in canola stubble.

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