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SHORT COMMUNICATION

Fluroxypyr-resistant kochia [*Bassia scoparia* (L.) A.J. Scott] confirmed in Alberta

Charles M. Geddes, Teandra E. Ostendorf, Mallory L. Owen, Julia Y. Leeson, Shaun M. Sharpe, Scott W. Shirriff, and Hugh J. Beckie

Abstract: Recent confirmation of dicamba-resistant kochia [*Bassia scoparia* (L.) A.J. Scott] in Alberta warrants investigation of resistance to other commonly used synthetic auxin herbicides like fluroxypyr. A randomized-stratified survey of 305 sites in Alberta was conducted in 2017 to determine the status of fluroxypyr-resistant kochia. Overall, 13% of the kochia populations were fluroxypyr-resistant. Only 4% of the populations were both fluroxypyr- and dicamba-resistant, indicating that different mechanisms may confer resistance to these herbicides. When combined with estimates of dicamba resistance, about 28% of the kochia populations sampled in Alberta in 2017 were resistant to at least one synthetic auxin herbicide.

Key words: herbicide resistance, *kochia scoparia*, surveillance, survey, synthetic auxin.

Résumé : La confirmation récente de la présence de kochie [*Bassia scoparia* (L.) A.J. Scott] résistante au dicamba en Alberta justifie qu'on vérifie la résistance de l'adventice à d'autres herbicides synthétiques courants à base d'auxine, tel le fluroxypyr. En 2017, les auteurs ont effectué une enquête randomisée et stratifiée sur 305 sites de la province en vue d'établir si la kochie résistait au fluroxypyr. Dans l'ensemble, treize pour cent des peuplements de kochie résistaient à l'herbicide. Quatre pour cent seulement des peuplements résistaient à la fois au dicamba et au fluroxypyr, signe que la résistance à ces herbicides pourrait résulter de mécanismes différents. Quand on combine ces résultats à l'estimation de la résistance au dicamba, on peut dire qu'environ 28 pour cent des peuplements de kochie échantillonnés en Alberta en 2017 résistaient à au moins un herbicide synthétique à base d'auxine. [Traduit par la Rédaction]

Mots-clés : résistance aux herbicides, *Kochia scoparia*, surveillance, enquête, auxine synthétique.

Introduction

Kochia [*Bassia scoparia* (L.) A.J. Scott] is a summer-annual tumbleweed that is native to Eurasia, but introduced to North America in the mid- to late- 1800s (Friesen et al. 2009). Since its introduction, kochia has spread to nearly all Canadian provinces and the continental United States except for a few eastern jurisdictions. In 2017, kochia was the 15th most abundant weed species remaining after post-emergence herbicide application among annual field crops in Alberta, and the most abundant weed species in the Mixed Grassland ecoregion (Leeson et al. 2019). Kochia was most abundant in lentil (*Lens culinaris* Medik.), followed by durum (*Triticum durum* Desf.), spring wheat (*Triticum aestivum* L.), and field pea (*Pisum sativum* L.).

Kochia has become one of the worst agricultural weed problems in the southern Canadian Prairies and western United States due, in part, to unique biological

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characteristics that facilitate its spread in semi-arid environments; and also unfettered selection for herbicide resistance (Kumar et al. 2019). Early germination and emergence, prolonged emergence periodicity, prolific seed production, robust abiotic stress tolerance (to heat, drought, and salinity), and rapid population turnover due to short seed longevity in the soil seedbank, facilitate growth in harsh environments, aid in evasion of herbicidal control, and expedite evolution of herbicide resistance (Friesen et al. 2009; Beckie et al. 2018; Kumar et al. 2019). Protogynous flowering in kochia aids rapid spread of herbicide resistance traits due to an initial period of cross-pollination followed by self-pollination to ensure reproductive fitness (Beckie et al. 2016). Upon senescence, the tumbleweed breaks off at the stem and is blown across the landscape by prevailing winds, resulting in seed dispersal among multiple fields in a single year (Beckie et al. 2016). This unique combination of efficient seed- and pollen-mediated gene flow can result in unprecedented spread of herbicide resistance traits within a short time frame.

In Canada, acetolactate synthase (ALS) inhibitor-resistant kochia was confirmed first in Saskatchewan and Manitoba in 1988, and subsequently in Alberta in 1989 (Kumar et al. 2019). After about two decades, ALS inhibitor-resistant biotypes comprised nearly all kochia populations in western Canada (Beckie et al. 2013, 2019). Glyphosate-resistant (GR) kochia was found first in Canada in Warner County, Alberta in 2011, following initial reports of the GR biotype in Kansas in 2007 (Beckie et al. 2013; Kumar et al. 2019). A 2012 survey of Alberta identified glyphosate resistance in 4% of the kochia populations sampled (Hall et al. 2014). After five years, this biotype had spread to or evolved in 50% of the populations sampled in Alberta (Beckie et al. 2019). The 2017 survey of Alberta also reported dicamba resistance in 18% of the kochia populations, while 10% were triple herbicide-resistant to ALS inhibitors, glyphosate, and dicamba. Dicamba-resistant kochia was discovered originally in Montana in 1993/1994, and has been now reported in Nebraska, North Dakota, Idaho, Colorado, Kansas, and Saskatchewan (Jha et al. 2015; Kumar et al. 2019). Many of these reports document kochia with resistance to dicamba alone or in combination with other synthetic auxins like 2,4-D or fluroxypyr (Crespo et al. 2014; Jha et al. 2015; Kumar et al. 2019; Westra et al. 2019).

Auxinic herbicide-resistant kochia in Alberta will limit herbicide options for control of these biotypes in cereal crops, like wheat, and also other uses like chemical fallow (Beckie et al. 2019; Torbiak et al. 2021*a*, 2021*b*). There is a need to understand whether auxinic herbicide-resistant kochia populations in Alberta are resistant to dicamba only, or also to other synthetic auxins. Several farmer reports suggest lack of kochia control using fluroxypyr, but prior to this study no evidence was available to support these claims. This study was designed to determine whether fluroxypyr-resistant (FR) kochia biotypes occur in Alberta, and if confirmed, identify the incidence of FR biotypes within kochia populations while also documenting the frequency at which these populations are present in Alberta.

Materials and Methods

Kochia samples were collected using a randomized survey of 305 sites in southern Alberta in the fall of 2017. Sites were predetermined at the township scale, and the number of sites within each ecodistrict (area of similar soil, vegetation, landform, and land use within an ecoregion) was stratified based on arable land base. The sites included both cropland and ruderal areas like oil wells, roadsides/ditches, and railway rights-of-way. The sites were visited post-harvest during a 3 wk period in late September to early October. Aboveground reproductive biomass was collected from 10–20 randomly selected mature kochia plants at each site, and the composite plant sample representing the kochia population was dried at room temperature. The populations were threshed in isolation to prevent cross-contamination, then screened for herbicide resistance at the Lethbridge Research and Development Centre near Lethbridge, Alberta.

The samples were the same as those screened for resistance to tribenuron/thifensulfuron, glyphosate, and dicamba by Beckie et al. (2019). The current study was designed subsequently to build on the research reported by Beckie et al. (2019) to characterize potential cross-resistance to fluroxypyr in Alberta kochia populations. Seeds from each kochia population were planted in 52 cm × 26 cm × 5 cm flats containing a modified Cornell soilless potting mixture supplemented with 756 mg N, 958 mg P, and 505 mg K L^{-1} mixture. The seedlings present within each flat were counted prior to herbicide treatment. A minimum of 100 seedlings from each population were treated with fluroxypyr (Prestige^{TM} XCA, Corteva Agriscience, Calgary, AB) at a rate of 140 g a.e. ha^{-1} when they reached 3–5 cm in height. The discriminating fluroxypyr dose was chosen based on unpublished dose-response experiments and those reported for populations from Montana (Jha et al. 2015). A moving-nozzle cabinet sprayer equipped with a flat-fan TeeJet® 8002VS nozzle (Spraying Systems Co. Wheaton, IL) was used to apply the herbicide in a single pass over the foliage at 50 cm height. The sprayer was calibrated to deliver 200 L ha^{-1} spray solution at 275 kPa when travelling at 2.4 km hr^{-1}. After treatment, the flats were placed in the greenhouse following a completely randomized design. The greenhouse conditions before and after herbicide treatment included 20/18 °C day/night temperature with a 16 hr photoperiod supplemented with 100 μmol m^{-2} s^{-1} light, and a daily watering regime. The experiment was conducted twice with each experimental run separated spatially (in a different greenhouse) and temporally (at a different time).

Individual plants within each population were rated as susceptible (dead or nearly dead) or resistant

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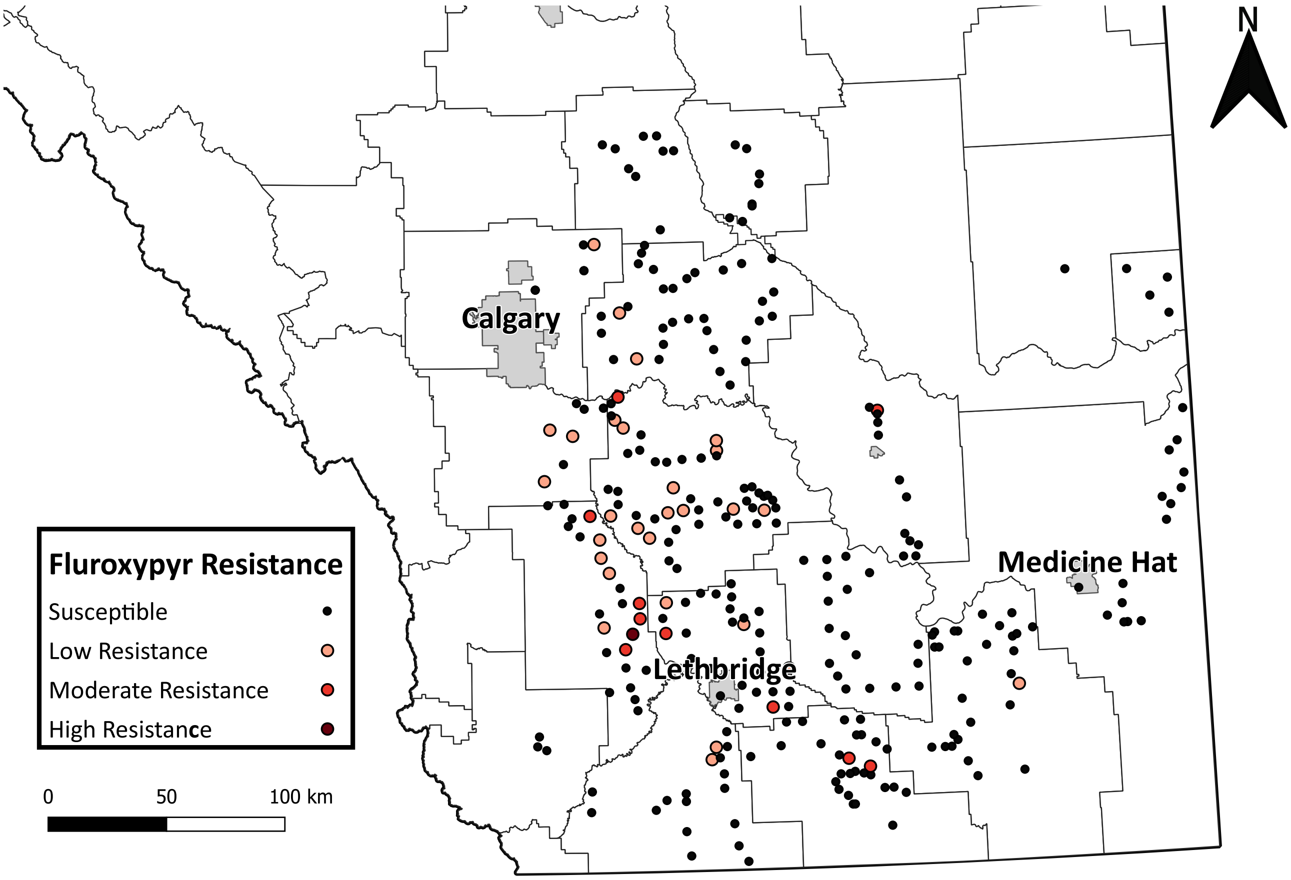
Fig. 1. Fluroxypyr-resistant kochia in Alberta in 2017. Low, moderate, and high resistance indicate the incidence of resistant individuals within each population categorized as 1%–20%, 21%–60%, and 61%–100%, respectively. Base layer: Municipality Boundaries (Altalis Ltd., Calgary, AB, www.altalis.com). Map projection: NAD83/Alberta 10-TM. [Colour online.]



(some injury but new growth, or no injury) 4 wk after treatment by comparing with herbicide-treated and untreated resistant and susceptible control populations. Due to the symptomology of fluroxypyr injury, and lack of complete chlorosis or necrosis in fluroxypyr-treated kochia, plants were considered resistant only if they showed no visible injury or if they exhibited regrowth from the apical meristem. Plants were considered susceptible if they lacked regrowth from the apical meristem even if they exhibited lateral regrowth. The incidence of FR individuals within each flat was determined as a percentage of the number of individuals treated. Each population was categorized as susceptible, or low, moderate, or high resistance when the incidence of resistance was 0%, 1%–20%, 21%–60%, or 61%–100%, respectively. Maps were developed using QGIS 3.12 (QGIS Geographic Information System, Open Source Geospatial Foundation).

Results and Discussion

Of the 305 sites sampled, kochia populations from 294 sites contained enough viable seed for resistance diagnostics. Overall, 13% of the kochia populations were FR, and these populations were found in 10 of the 17 counties sampled (Fig. 1). Dicamba-resistant kochia was also found in 10 counties in 2017 (Beckie et al. 2019), however, only six counties overlapped among the FR and DR populations. Fluroxypyr-resistant but not DR populations were found in the counties of Rocky View, Foothills, Wheatland, and Newell, while DR but not FR populations were found in Taber, Cypress, Acadia, and Special Area #3 (Beckie et al. 2019). In contrast, Beckie et al. (2019) found GR kochia in all but one of the counties surveyed in 2017, while all populations were ALS inhibitor-resistant.

The greatest confirmation frequency of FR kochia was along the highway 2 corridor between Lethbridge and Calgary, including the counties of Willow Creek (41% of populations were FR), Foothills (33%), Vulcan (24%), and Lethbridge (19%) (Fig. 2). This suggests that farmers located in these counties are at greatest risk of FR kochia biotypes spreading among fields. Fluroxypyr-resistant kochia was found at the greatest frequency in small-grain cereal crops (23% of population were FR), followed by canola (*Brassica napus* L.) (15%), ruderal areas (7%), chemical fallow (6%), and pulse crops (3%). Dicamba-resistant kochia, by comparison, was confirmed at the

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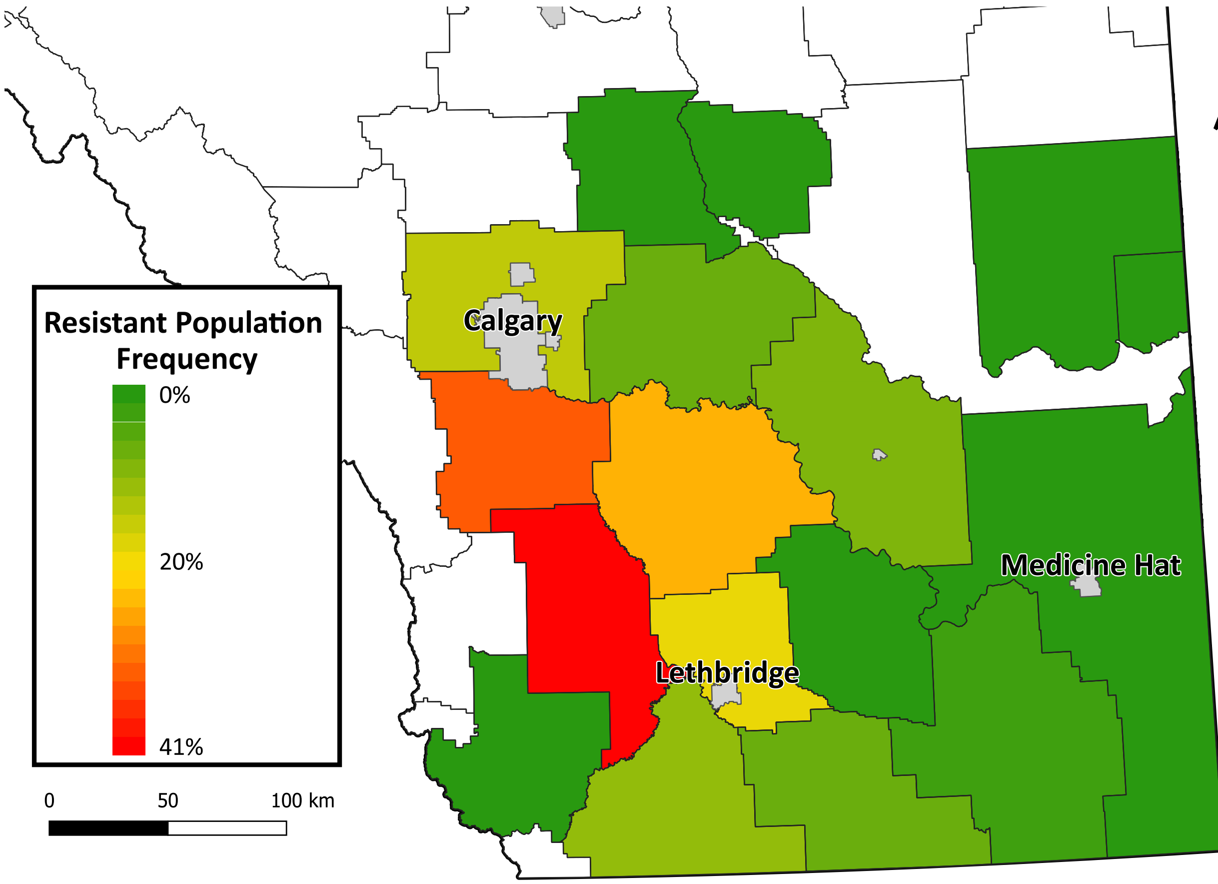
Fig. 2. Frequency of kochia populations confirmed resistant to fluroxypyr in each county sampled during a 2017 survey of Alberta. Base layer: Municipality Boundaries (Altalis Ltd., Calgary, AB, www.altalis.com). Map projection: NAD83/Alberta 10-TM. [Colour online.]

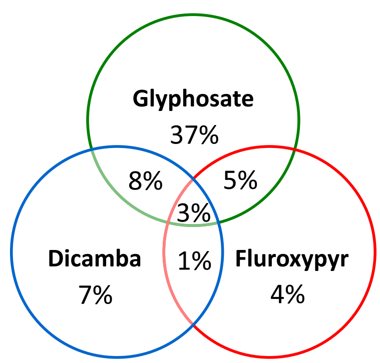


greatest frequency in small-grain cereals (27%), followed by chemical fallow (22%), pulses (20%), other oilseeds (17%), canola (12%), ruderal areas (11%), and corn (*Zea mays* L.) (10%) (Beckie et al. 2019).

The kochia populations were segregating for fluroxypyr resistance with a mean incidence of FR individuals of 18% and a median of 12% (SD = 8.8). The majority of FR populations (9% of total populations) had low resistance (incidence of 1%–20%). Low resistance within these populations is indicative of the early stages of resistance evolution. These populations often remain undetected by farmers or agronomists, but are segregating for resistance, indicating that problems with inadequate control are imminent. Moderate (incidence of 21%–60%) and high resistance (61%–100%) were present in 3% and 1% of the populations tested, respectively. Fluroxypyr-resistant kochia populations with moderate and high resistance would be likely to cause immediate problems if fluroxypyr-based herbicides were used for their control.

Of the 294 kochia populations tested, 13% were FR, 19% were DR, and 53% were GR (Fig. 3). The exclusion of 11 populations with limited seed supply caused the slight discrepancy between these (DR and GR) frequencies and those reported by Beckie et al. (2019). In comparison, a survey of Colorado from 2012–2014 did not find FR kochia, but did find resistance to dicamba and glyphosate in 33% and 49% of the 171 populations tested, respectively

Fig. 3. Frequency of kochia populations ($n = 294$) confirmed multiple herbicide-resistant to acetolactate synthase inhibitors (all populations) and glyphosate, dicamba, and (or) fluroxypyr in a 2017 survey of Alberta. Glyphosate and dicamba data adapted from Beckie et al. (2019). [Colour online.]



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(Westra et al. 2019). A 2009–2010 survey of 71 kochia populations in Nebraska found one DR kochia population in an irrigated corn field (Crespo et al. 2014). Previous surveys of Alberta (2012), Saskatchewan (2013), and Manitoba (2013) did not find DR kochia in western Canada (Hall et al. 2014; Beckie et al. 2015); however, a subsequent 2017 survey of Alberta reported that 18% of the populations tested were DR (Beckie et al. 2019). Fluroxypyr resistance was not assessed during previous kochia surveys of the Canadian Prairies, although in 2015 a sample from a wheat field in Saskatchewan exhibited low resistance to dicamba and fluroxypyr (Beckie et al. 2019).

Only 4% of the kochia populations tested in the current study were resistant to both fluroxypyr and dicamba, suggesting that overall 28% of populations sampled from Alberta in 2017 were resistant to at least one synthetic auxin herbicide, while 16% were triple herbicide-resistant to ALS inhibitors, glyphosate and a synthetic auxin (Fig. 3). The low overlap among DR and FR kochia populations in Alberta suggests that separate mechanisms may confer resistance to dicamba and fluroxypyr.

Limited alternative herbicide options to control auxinic herbicide-resistant kochia post-emergence in cereal crops (Beckie et al. 2019; Torbiak et al. 2021*b*) indicates that further selection pressure is inevitable due the broad land base planted to cereals in western Canada. To alleviate further selection for these biotypes, farmers are advised to implement alternative chemical and non-chemical weed control practices. Management of herbicide-resistant kochia should exploit its short-lived seedbank persistence by preventing seed production and return to the soil seedbank (Geddes and Davis 2021). In addition, a community-based approach will be required to mitigate introduction and spread of this problematic weed among farms, thereby limiting transfer of resistance alleles from field to field.

Competing Interests

The authors declare no competing interests.

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Contributors' Statement

CMG: Conceptualization, methodology, funding acquisition, investigation, supervision, validation, formal analyses, visualization, writing – original draft, writing – reviewing and editing. TEO, MLO, SMS, SWS, and JYL: Investigation, writing – reviewing and editing. HJB: Conceptualization, methodology, investigation, writing – reviewing and editing.

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