A hidden threat: widespread Group B herbicide resistance in brome across south-eastern Australia

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Summary *Bromus diandrus* Roth (great brome or brome) is a troublesome weed across many regions of the South Australian and Victorian wheat belt, particularly in the lower rainfall areas. Random weed surveys conducted since 2008 have identified that brome is more prevalent in lower rainfall regions. In the South Australian Mallee, Eyre Peninsula, Victorian Mallee and Wimmera, brome was identified in at least 40% of fields. Strong selection pressure with Group B herbicides in wheat has resulted in resistance to herbicides such as sulfosulfuron and mesosulfuron (both sulfonylureas) and pyroxsulam (triazolopyrimidine). In the South Australian Mallee in a random weed survey conducted in 2012, 45% and 50% of brome samples exhibited resistance to mesosulfuron and pyroxsulam, respectively. In contrast, no resistance to the Group B imidazolinone herbicide mixture (imazapyr + imazamox) was detected. No resistance to the Group A herbicides was detected in the SA Mallee suggesting that use of these herbicides in broadleaf crops should be effective in the majority of cases. However, in south-eastern SA where use of Group A herbicides is more prevalent, 14% of brome samples exhibited resistance to haloxyfop. This result indicates that Group A herbicides should be used with caution and the overuse of this mode of action could further increase resistance. Weed control with pre-emergent herbicides with limited residual activity is difficult because brome has a wide germination window. However, in field trials a mixture of pyroxasulfone with triallate provided the best level of control.

Keywords Herbicide resistance, great brome, pyroxasulfone, triallate.

INTRODUCTION

Bromus diandrus is a troublesome weed of grain production in southern Australia. This species is common on lighter textured soils in South Australia and Victoria. Brome competition in wheat can result in yield loss as high as 50% (Gill *et al.* 1987). The introduction of reduced tillage systems has led to an increase in the incidence of brome in crops in southern Australia (Kon and Blacklow 1988, Heenan *et al*. 1990).

In continuously cropped fields, brome populations have evolved extended dormancy that reduces their emergence until after the crop has been sown (Kleemann and Gill 2006, 2013). This feature means that post-emergent herbicides tend to be more effective and have been preferred for the control of this weed species (Kleemann and Gill 2009a).

The reliance on post-emergent herbicides has resulted in the evolution of resistance in brome populations to herbicides (Boutsalis and Preston 2006, Boutsalis *et al.* 2012a, Owen *et al.* 2012). Failure of post-emergent herbicides to control brome will complicate management for growers. Recently, a new pre-emergent herbicide, pyroxasulfone, has been introduced to Australia (Boutsalis *et al.* 2010, 2014, Walsh *et al.* 2011). Due to its extended residual activity it may provide improved control of brome compared with alternative pre-emergent products.

This research surveyed brome populations across South Australia and Victoria to determine the extent of resistance to post-emergent herbicides. It also examined the efficacy of pyroxasulfone used alone or in mixtures to control brome in cereal production.

MATERIALS AND METHODS

Survey Random weed surveys were conducted every year from 2008 to 2012. Fields were randomly chosen within key grain-producing districts in South Australia and Victoria (Boutsalis *et al*. 2012b). Sampling was performed just prior to crop harvest. Within each district, fields were selected by travelling for a pre-determined distance (5 or 10 km) on minor roads where possible. At each stop, a single field was surveyed. Sampling of mature brome panicles commenced 10 m in from the edge of the crop and continued in an inverted W pattern through at least 1 ha of the field. When a large patch of brome plants was encountered, up to 10 panicles were collected from the patch. Sampling was discontinued once about 20 panicles had been collected or after 30 min, whichever occurred first. Fields that had been harvested were still sampled since intact brome panicles with seed still occur below the harvest height. Panicles were placed in labelled paper bags and the location of each sample recorded by a global positioning system (GPS) navigational unit recording longitude and latitude. The populations were kept in a covered enclosure and subjected to fluctuating summer temperatures for 4 months to allow after-ripening of the seed.

Resistance screening Brome seed was sown at 1 cm depth into 20 × 30 cm trays containing cocoa peat potting mix (Boutsalis *et al.* 2012). Upon germination, 10 seedlings were transplanted into 0.9 L pots with dimensions 10 × 15 cm representing a density of 67 plants m^{-2}. One pot per herbicide treatment including an untreated check was sown. Pots were watered as required. Each trial was conducted outdoors during autumn and winter under environmental conditions consistent with those that occur when these herbicides are normally applied in the field. Before treatment, the number of seedlings per pot was counted.

Mesosulfuron-methyl (Atlantis®) at 9.9 g ha^{-1} and pyroxsulam (Crusader®) at 15 g ha^{-1} were applied at the Z11 to Z12 growth stage, whereas haloxyfop-R-methyl (Verdict®) at 39 g ha^{-1} and imazapyr + imazamox (Intervix®) at 9 + 19.8 g ha^{-1} were applied at growth stage Z13 to Z21 (Zadoks *et al.* 1974). Adjuvants were added as recommended on the herbicide labels. Herbicide was applied using a laboratory herbicide applicator with a twin-nozzle 110-01 standard flat fan moving boom situated 40 cm above the pots and delivering 103 L ha^{-1} at 1 m s^{-1} and 250 kPa. Non-ionic surfactant (BS1000) was added to Verdict, Atlantis and Crusader at 0.2% (v/v), whereas 1% (v/v) mineral oil (Supercharge®) was added to Intervix. Survival of plants in the pot tests was assessed 21 to 28 d after treatment by counting the surviving plants and dividing by the total number of plants that were present in each pot before herbicide treatment.

Field trials of pre-emergent herbicides to control brome populations in wheat From 2010 to 2012, a total of five field trials were conducted in South Australia and Victoria to examine the control of brome in wheat with pre-emergent herbicides. Trials were conducted in Victoria at Yaapeet in 2010 and 2011 and at Pira in 2012. In South Australia trials were conducted at Pallamana in 2011 and Balaklava in 2012.

Trials were sown to various wheat cultivars using knife-point and press-wheel seeding equipment. Herbicides were applied prior to the seeding operation (IBS) except for the split application of pyroxasulfone, where the second application was applied post-sow pre-emergent (PSPE).

Herbicides used in the trials were: trifluralin (TriflurX®) + pendimethalin (Stomp®) at 480 g ha^{-1} + 660 g ha^{-1}, trifluralin + metribuzin (Lexone®) at 480 g ha^{-1} + 150 g ha^{-1}, pyroxasulfone (Sakura®) at 100 g ha^{-1}, pyroxasulfone + metribuzin at 100 g ha^{-1} + 150 g ha^{-1}, pyroxasulfone + triallate (Avadex Xtra®) at 100 g ha^{-1} + 1000 g ha^{-1} and pyroxasulfone IBS at 75 g ha^{-1} followed by pyroxasulfone PSPE at 25 g ha^{-1}. The efficacy of herbicides in the trials was assessed prior to crop harvest by counting the number of brome panicles present.

RESULTS

Fields in key grain growing regions were surveyed between 2008 and 2012. Brome was detected in all the regions surveyed but was more prevalent in the lower rainfall areas such as the South Australian Mallee, Eyre Peninsula and western Victoria where 60%, 40% and 56% of the fields contained brome, respectively (Table 1).

Resistance to the Group A herbicide haloxyfop was identified in the Mid-north of South Australia, western Victoria and the South East of South Australia. The greatest incidence of resistance was detected in the intensively cropped South East region where 14% of the samples were resistant.

Resistance to the Group B herbicides was identified in all regions where brome was collected. The incidence of resistance to the sulfonylurea and tria-

Table 1. Brome populations resistant to Group A and Group B herbicides in South Australia and Victoria. The number of samples collected in each area is given with the incidence brome in that region in parentheses. Numbers below each herbicide are the percentage of populations collected with resistant individuals. A dash (–) indicates no test with that herbicide.

Region	Year	Samples (no. with incidence)	Haloxyfop (%)	Mesosulfuron (%)	Pyroxsulam (%)	Imazapyr + imazamox (%)
SA Mallee	2012	153 (60)	0	45	50	0
SA – South East	2012	26 (21)	14	16	13	0
SA – Mid-north	2008	36 (24)	2	2	–	–
SA – Eyre Peninsula	2009	58 (40)	0	5	–	–
Vic – Western	2010	71 (56)	7	37	–	–
Vic – Northern	2011	15 (8)	0	7	0	–

zolopyrimidine herbicides ranged from low in most areas to high in the SA Mallee and western Victoria. Where tested, the imidazolinone herbicide mixture Intervix was still effective.

Brome control in field trials was variable depending on environmental conditions. Across the trials reduction in brome panicles ranged from 11 to 94%. All treatments performed poorly (less than 50% reduction in brome panicles) in at least one trial (Figure 1). Across all trials, trifluralin + metribuzin provided the lowest average control of 44% reduction in panicles. Pyroxasulfone applied alone IBS provided an average of 50% reduction in brome panicles. The most effective treatment on average was pyroxasulfone + triallate, which reduced brome panicles by an average of 73%, followed by the split application of pyroxasulfone, which reduced brome panicles by an average of 68%. For both of these treatments, reduction in brome panicles was >70% in four of the five trials conducted, but <35% in the remaining trial.

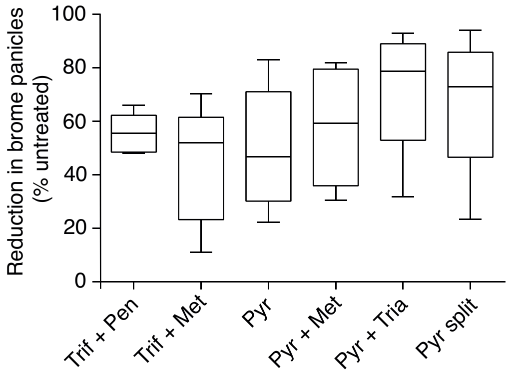

Figure 1. Summary of five trials of pre-emergent herbicides for brome control. The central bar is the mean of the five trials and the whiskers are the maximum and minimum. Herbicides used were trifluralin (Trif), pendimethalin (Pen), metribuzin (Met), pyroxasulfone (Pyr) and triallate (Tria). Split indicates the herbicide was split across IBS and PSPE applications.

DISCUSSION

The incidence of herbicide resistance in brome is increasing in southern Australia. Resistance to the Group A herbicides was first reported in north-western Victoria (Boutsalis and Preston 2006), but now is also present in several areas of South Australia (Table 1). Resistance to Group A herbicides occurs principally because of the intensive use of these herbicides in break crops and pastures as part of the rotation with cereals (Boutsalis and Preston 2006). Variation in the spectrum of resistance among Group A herbicides exists (Boutsalis *et al.* 2012a).

Resistance to Group B herbicides in brome was reported after resistance to Group A herbicides in South Australia and Victoria (Boutsalis *et al.* 2012a). This is likely due to relative ineffectiveness of many common Group B herbicides on brome. The introduction of more effective Group B herbicides such as mesosulfuron-methyl and pyroxsulam in wheat will have increased the selection pressure for resistance to this mode of action. In addition, the frequency of mutations giving resistance to Group B herbicides can be high in populations before the herbicides are used (Preston and Powles 2002). These two factors have contributed to the rapid increase in resistance to Group B herbicides in brome, which now affects 50% of populations in the South Australian Mallee.

A strong shift towards imidazolinone herbicides for brome control has occurred (Kleemann and Gill 2009b) with the advent of imidazolinone tolerance in crops. As yet the survey data show no resistance to imidazolinone herbicides. However, populations of brome with resistance to imidazolinone herbicides are known to be present (Boutsalis *et al*. 2012a) and it is likely that continued reliance on these herbicides will lead to increased resistance.

Where resistance to post-emergent herbicides occurs alternative options for brome control are limited. Pre-emergent herbicides are often ineffective (Kleemann and Gill 2009a) due to the delayed emergence of brome in cropped fields (Kleemann and Gill 2006, 2013). Trials with pyroxasulfone alone and in mixtures with other herbicides suggest that this herbicide may have some utility in controlling brome (Figure 1). The best levels of control (>90% reduction in panicles) occurred with split applications of pyroxasulfone or with a mixture of pyroxasulfone + triallate. Pyroxasulfone alone was often less effective.

A large variation in control with pyroxasulfone alone or in mixtures has been observed with as little as a 30% reduction in panicles in some seasons. Pre-emergent herbicides are highly dependent on moisture for activity and poor moisture availability at key times may be responsible for their variable effectiveness. In situations where brome develops resistance to post-emergent herbicides, pre-emergent herbicides are unlikely to provide sufficient control and other weed management tactics will have to be employed.

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