New mode of action herbicides to combat herbicide resistant annual ryegrass (*Lolium rigidum*) in Australian cereal production

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Summary Herbicide resistance in annual ryegrass across southern Australia is currently a major issue for grain producers. Currently annual ryegrass (*Lolium rigidum* Gaudin) has evolved resistance to all post-emergent herbicides that can be used to control it in cereal crops and to the pre-emergent herbicide trifluralin. No new herbicide modes of action for the control of annual ryegrass have been marketed since the 1980s. In the past 5 years, research has been conducted with new mode of action herbicides that are selective in cereals. Prosulfocarb + S-metolachlor and pyroxasulfone effectively controlled 20 trifluralin-resistant populations of annual ryegrass in pot trials. Field trials have determined that prosulfocarb + S-metolachlor, pyroxasulfone and dimethenamid-P could control trifluralin-resistant annual ryegrass when applied and incorporated by sowing (IBS) in the field. Prosulfocarb + S-metolachlor and pyroxasulfone were safe in barley, but dimethenamid-P caused unacceptable damage. Improved control of annual ryegrass was achieved by splitting the herbicide application between IBS and post-sow, pre-emergent (PSPE).

Keywords Barley, prosulfocarb, S-metolachlor, dimethenamid-P, pyroxasulfone, trifluralin resistance, *Lolium rigidum*.

INTRODUCTION

The most serious weed across southern Australia in cereal crops is *Lolium rigidum* Gaudin (annual ryegrass). Coupled with the widespread adoption of minimum tillage, the reliance on modern pre- and post-emergent selective herbicides has soared. The main herbicide groups used for controlling ryegrass are the dinitroaniline (DN), aryloxyphenoxypropionate (APP), cyclohexanedione (CHD) and sulfonylurea (SU) herbicides. Reliance on these herbicides has been increasing after their introduction from the 1970s with the first cases of resistance to these herbicides reported a decade later (Heap and Knight 1986, Howat 1987). This led to a situation where farmers have no selective herbicides available to control annual ryegrass in cereal crops.

Random surveys of over 1000 fields across southern Australia in the past decade have revealed alarming levels of resistance in ryegrass, particularly to APP and SU herbicides (Boutsalis *et al.* 2008). In addition, in South Australia, at least one-third of fields have significant levels of resistance to the pre-emergence herbicide trifluralin. For this reason, extensive effort by chemical companies has resulted in the introduction of new mode of action herbicides to the Australian market. One product, Boxer Gold™ (Syngenta) – a mixture of S-metolachlor and prosulfocarb, has been available for 2 years whereas pyroxasulfone (Bayer CropScience) and dimethenamid-P (Nufarm) are still in development. Boxer Gold™ and pyroxasulfone are selective in cereal crops whereas dimethenamid-P is being developed for use in legume crops.

The aim of this research was to test the effectiveness of new mode of action herbicides in controlling annual ryegrass resistant to trifluralin.

MATERIALS AND METHODS

Efficacy of new pre-emergent herbicides on 20 trifluralin-resistant annual ryegrass populations in pots Twenty annual ryegrass samples sent by farmers for commercial resistance testing and confirmed to possess varying degrees of resistance to trifluralin (in previous tests) were tested with trifluralin, prosulfocarb + S-metolachlor and pyroxasulfone. In addition, a standard susceptible biotype (SLR4) and two trifluralin-resistant standard biotypes SLR31 and L163 were used as controls. Each herbicide treatment was replicated twice and the mean survival calculated. The herbicides were applied to 0.1 g of seed placed on the surface of potting mix in 10 cm^2 square pots using a laboratory moving boom pesticide applicator. The herbicide was applied in the equivalent of 109 L ha^{-1} water at a pressure of 250 kPa and a speed of 1 m s^{-1} using Tee-Jet 001 nozzles. After herbicide application, 0.5 cm of soil was placed on top of the seed. As determined from previous dose response pot trials (data not shown), the herbicides used were trifluralin at 200 g a.i. ha^{-1}, prosulfocarb + S-metolachlor at 1150 g a.i. ha^{-1} and pyroxasulfone at 50 g a.i. ha^{-1}. These rates were found to be the minimum rates required to prevent germination of several susceptible annual ryegrass biotypes in previous pot trials.

Efficacy of new pre-emergent herbicides on a trifluralin-resistant ryegrass population in the field A field trial was conducted during the 2009 growing season in a farmer's field, near the township of Roseworthy located approximately 50 km north of Adelaide, South Australia. A pot test conducted the previous year (data not shown) confirmed the ryegrass from this field exhibited a high level of resistance to trifluralin. Various pre-emergence herbicides were applied IBS (incorporated by sowing) in a field sown with a barley crop at 22 cm wide rows (Table 2). The IBS system tends to move herbicide away from the crop row and can result in ryegrass germinating in soil containing little or no herbicide. An herbicide split application was included, testing a mixture of 75% of the herbicide IBS and 25% of the herbicide PSPE (post sowing pre-emergent) to determine if weed control was improved in the crop row. The trial was arranged as a randomised complete block design with four replicates. Several measurements were taken including early crop vigour, ryegrass panicles and ryegrass seedling counts at different timings. Data for ryegrass panicles produced at the end of the season are presented here. Data were subjected to ANOVA and treatment means were compared by LSD at 5% level of significance.

RESULTS

Efficacy of new pre-emergent herbicides on 20 trifluralin-resistant annual ryegrass populations in pots The susceptible annual ryegrass population SLR4 was completely controlled with no emergence by the application of trifluralin (Table 1). The two standard trifluralin-resistant annual ryegrass populations, SLR31 and L163, were not controlled by trifluralin. Trifluralin failed to control any of the 20 populations of annual ryegrass from South Australia and Victoria, with emergence ranging from 27% to 100%. Prosulfocarb + S-metolachlor completely inhibited emergence of all annual ryegrass populations except L163, where 2% of the population emerged. Likewise, pyroxasulfone completely inhibited emergence of annual ryegrass in all populations, except 03140, where 2% of the population emerged.

This experiment demonstrated that prosulfocarb + S-metolachlor and pyroxasulfone could control a wide variety of annual ryegrass populations that were resistant to trifluralin. The rates of trifluralin, prosulfocarb + S-metolachlor and pyroxasulfone used were lower than those used in the field.

In this pot trial it is likely that the performance of the pre-emergence herbicides was greater than would be expected in the field due to the lack of stubble, perfect placement of the herbicide and adequate soil cover.

Efficacy of new pre-emergent herbicides on a trifluralin-resistant ryegrass population in the field A field trial was established to determine the efficacy of pre-emergent herbicides on trifluralin-resistant annual ryegrass. Even under good moisture conditions for herbicide efficacy the maximum label rate of trifluralin (1440 g a.i. ha^{-1}) or the mixture of trifluralin + triallate had little effect on controlling annual ryegrass in the field trial (Table 2). Trifluralin at 720 g a.i. ha^{-1} + triallate at 800 g a.i. ha^{-1} reduced panicle numbers in this population by 38%. Prosulfocarb + S-metolachlor and pyroxasulfone provided much greater reductions in panicle numbers when the herbicides were applied IBS. Pyroxasulfone provided 78% reduction in annual ryegrass panicle numbers.

Where the herbicides were applied as a split treatment with 75% of the rate IBS and 25% of the

Table 1. Emergence (% of untreated) selected trifluralin-resistant annual ryegrass populations after treatment with trifluralin, prosulfocarb + S-metolachlor or pyroxasulfone.

Sample No.	State	Trifluralin 200 g a.i. ha^{-1}	Prosulfocarb + S-metolachlor 1000 g a.i. ha^{-1} + 150 g a.i. ha^{-1}	Pyroxasulfone 50 g a.i. ha^{-1}
L126	SA	76	0	0
L142	SA	100	0	0
L153	VIC	100	0	0
L155	VIC	100	0	0
L163	SA	85	0	0
L166	SA	43	0	0
L193	VIC	67	0	0
L204	SA	60	0	0
L229	VIC	80	0	0
L231	VIC	81	0	0
03024	SA	71	0	0
03040	SA	92	0	0
03043	SA	63	0	0
03054	SA	58	0	0
03088	SA	60	0	0
03128	SA	100	0	0
03131	SA	50	0	0
03140	SA	49	0	2
03077	SA	33	0	0
03053	SA	27	0	0
SLR4	SA	0	0	0
SLR31	SA	22	0	0
L163	SA	100	2	0

rate PSPE, control of annual ryegrass improved. No reduction in crop vigour was observed except for the dimethenamid-P treatments, which reduced crop vigour by 10% (data not shown).

DISCUSSION

Resistance to trifluralin in annual ryegrass populations is emerging as a major problem for cereal growers, particularly in South Australia (Boutsalis *et al.* 2006). The combination of resistance to trifluralin and to APP, CHD and SU cereal selective herbicides leaves grain growers with no effective herbicides for the control of annual ryegrass in cereals. This research has demonstrated that two new post-emergent herbicide products effectively control trifluralin-resistant annual ryegrass populations (Table 1). In addition, these herbicides controlled trifluralin-resistant annual ryegrass in the field (Table 2).

One of the problems that grain producers experience with the adoption of no-till farming systems is the lack of control of annual ryegrass within the crop row. This occurs because the herbicide treated soil is thrown out of the crop row onto the inter-row during the seeding operation. The availability of pre-emergent herbicides with greater crop safety compared with trifluralin and less need for soil incorporation offers an opportunity to obtain greater control of annual ryegrass in the crop row. The splitting of the herbicide between IBS and PSPE applications tended to increase control of annual ryegrass rather than decrease control (Table 2). This was achieved without reducing crop safety for prosulfocarb + S-metolachlor and pyroxasulfone.

Prosulfocarb, S-metolachlor and pyroxasulfone have a different mode of action to trifluralin. These new pre-emergent herbicides offer cereal growers the opportunity to obtain effective control of trifluralin-resistant annual ryegrass in wheat and barley. Both new herbicides are considered a moderate risk for resistance evolution and so will need to be used in rotation with other modes of action to delay the onset of resistance to the new products.

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Table 2. Annual ryegrass panicles (% of untreated) for various pre-emergent herbicide treatments in barley at 148 days after application at Roseworthy, South Australia in 2009.

Herbicide	Application timing[A]	Rate (g a.i. ha^{-1})	Panicle number (% of untreated)[B]
Trifluralin	IBS	720	73 b
Trifluralin	IBS	1440	100 a
Trifluralin + triallate	IBS	720 + 800	62 bc
Prosulfocarb + S-metolachlor	IBS	1200 + 300	42 cde
Dimethenamid-P	IBS	479	53 bcd
Pyroxasulfone	IBS	100	22 ef
Prosulfocarb + S-metolachlor	IBS + PSPE	(900 + 225) + (300 + 75)	31 ef
Dimethenamid-P	IBS + PSPE	319 + 160	34 def
Pyroxasulfone	IBS + PSPE	75 + 25	16 f
Untreated			100 a
P-value			0.0001
LSD (5% level)			21

[A] IBS: incorporated by sowing using knife points and press wheels; PSPE: post sowing pre-crop emergence.
[B] Means within columns followed by the same letter are not significantly different at the 5% level according to least significant difference (LSD) test.