Sensitivity of lentil genotypes to photosynthesis-inhibiting (Group C) herbicides

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Abstract
Lentil (*Lens Culinaris* M.) is a poor competitor with weeds and its sensitivity to herbicides make broad-leaf weed control challenging. Herbicide resistance due to overreliance on group B herbicides in herbicide resistant crop varieties has also become a concern. Group C herbicides control many broad leaf and some grass weeds. However, this group of herbicides have a low safety margin between phytotoxicity to weeds and to the lentil crop. Field experiments evaluated the Group C herbicide sensitivity of three lentil genotypes PBA Hurricane XT, PBA Jumbo and PBA Jumbo 2 in comparison to a new genotype (SP1333) with improved metribuzin tolerance. Diuron, simazine, metribuzin and terbuthylazine were applied post-sowing pre-emergence at various rates. All genotypes did not show sensitivity to 765 gai/ha of diuron and up to 3600 gai/ha of simazine and produced grain yield equivalent to their respective nil treatment. However, application of higher rates of metribuzin and terbuthylazine caused significant injury and a subsequent yield loss of up to 100%. SP1333 had better tolerance to lower rates of metribuzin, terbuthylazine and higher rates of diuron than PBA Hurricane XT, PBA Jumbo and PBA Jumbo 2, providing opportunity for breeding programs to develop varieties with improved tolerance to group C herbicides.

Key Words
Genetic variation, herbicide injury, lentil, Group C herbicides

Introduction
Lentil is a poor competitor with weeds due to short stature, slow early growth and slow canopy closure (Blackshaw et al. 2002). Grain yield loss from competition with weeds can range up to 84% if weeds are not controlled during the first four to six weeks after sowing (Mohamed et al. 1997). Growers in the no till farming system of Southern Australia predominantly use herbicides to control weeds (Brand et al. 2012). Acetolactate synthase inhibitors are among the most widely used herbicides for management of weeds in the Australian southern cropping region (Preston et al. 1999), and overreliance on these herbicides has contributed to rapid evolution of herbicide resistant weeds (Boutsalis at al. 2016). Thus, identifying effective alternative herbicide options is essential for sustainable weed management. Photosynthesis-inhibiting herbicides (Group C) control many broad leaf and some grass weeds. However, this group of herbicides (eg. metribuzin) have a low safety margin between phytotoxicity to weeds and to the lentil crop (Brand et al. 2012). For example, metribuzin and terbuthylazine applied either pre-emergent or pre-emergent and post sowing pre-emergent (PSPE) reduced lentil yield by up to 46% (Davey 2014). However, the sensitivity of lentil to herbicides varies with application rate, variety, soil type and environmental conditions such as soil moisture or rainfall intensity after herbicide application (Davey 2014). McMurray et al. (2018) reported significant variation in tolerance to metribuzin among lentil genotypes. There are also perceived differences between commercial lentil cultivars in sensitivity to Group C herbicides.

The aim of this study was to evaluate the sensitivity of lentil genotypes to PSPE application of various rates of diuron, metribuzin, simazine and terbuthylazine.

Methods
Experimental site and Design: Field experiments were conducted at Rupanyup (36^{o} 32’ 146’’S, 142^{o} 37’ 704’’E) and Curyo (35^{o} 47’ 117’’S, 142^{o} 46’ 675’’E), Victoria in 2017. The growing season rainfall was 298 mm and 243 mm at Rupanyup and Curyo, respectively. The Rupanyup site had black cracking clay soil with 0.99 % organic carbon and soil pH ($CaCl_2$) of 7.5. At Curyo the soil was a sandy loam and had 0.73 % organic carbon and soil pH of 7.3 in the top 10 cm.

The experiments were laid out in split plot design with three replications. The main plot factor comprised of various rates of diuron, metribuzin, simazine and terbuthylazine at Rupanyup, and metribuzin and terbuthylazine at Curyo (Table 1). The genotypes were randomly assigned to subplots. The sensitivity of

PBA Hurricane XT, PBA Jumbo and PBA Jumbo 2 to the herbicide treatments was evaluated and compared with a new genotype (SP1333) with improved tolerance to metribuzin.

Experimental Procedure: The experimental plots were 8 m long and 1.44 m wide at both locations. The crop was sown at 36 cm row spacing and 120 plants/m^2 between standing (30 cm high at Rupanyup and 15 cm at Curyo) stubble rows from the previous year`s wheat crop. Herbicide treatments were applied PSPE using a backpack sprayer calibrated to deliver 100 L/ha of spray solution. At sowing, all experimental plots were fertilized with a monoammonium phosphate (N-9.2, P-20.2, K-0, S-2.7 %) and zinc (2.5 %) blend at a rate of 80 and 60 kg/ha at Rupanyup and Curyo, respectively.

***Data collection and analysis*:** Dry matter yield at flowering was determined by cutting plants from 1.44 m^2 area at the center of the plots. Samples were oven-dried at 70°C for three days to constant moisture. Visual herbicide injury scores were recorded on a plot basis at 67 and 75 days after spraying (DAS) at Rupanyup and Curyo, respectively. At maturity, plots were harvested with a small plot harvester and grain yield recorded. All data were subjected to analysis of variance (ANOVA) using Genstat version 18 (VSN International, Hemel Hempstead, UK).

Results

***Herbicide Injury*:** Crop injury symptoms from PSPE application of Group C herbicides included stunting of growth, chlorosis, necrosis and complete plant death. At Rupanyup, no significant herbicide injury was observed in all genotypes from simazine applied at all application rates and diuron applied at 765 gai/ha (Table 1). At the higher application rates of diuron, SP1333 showed no significant injury, while PBA Hurricane XT showed the worst crop damage (Table 1). Metribuzin caused more crop injury than diuron. Responses to metribuzin were similar for PBA Hurricane XT, PBA Jumbo and PBA Jumbo2, with increasing damage as rates increased (Table 1). SP1333 showed significantly less damage at all application rates (Table 1). Terbuthylazine caused the highest crop injury when applied to PBA Hurricane XT, significantly greater than PBA Jumbo and PBA Jumbo2, while SP1333 showed the least symptoms (Table 1). At Curyo, relative trends in response to metribuzin and terbuthylazine were similar to Rupanyup, but symptoms were generally more severe (Table 1).

Table 1. Visual herbicide injury score (0= no damage, 100= plant death) from post-sowing pre-emergent application of various rates of Group C herbicides to lentil genotypes at Rupanyup (67 DAS) and Curyo (75 DAS), Victoria in 2017.

Active ingredient (g/ha)	Rupanyup				Curyo			
	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333
Nil	0a	0a	0a	0a	0a	0a	0a	0a
Diuron								
765	13a	0a	15ab	5a				
1530	33b	20b	30bc	8a				
3060	44bc	19b	24b	7a				
Metribuzin								
210	33b	33bc	30bc	10a	70c	73c	62b	47c
420	67e	63e	67d	30bc	97d	97d	95c	85de
840	87f	85f	90e	57	98d	100d	93c	100e
Simazine								
900	5a	0a	2a	2a				
1800	7a	2a	7a	0a				
3600	7a	2a	2a	2a				
Terbuthylazine								
750	40bc	13a	13ab	5a	30b	33b	15a	5a
1500	50cd	43cd	43c	15ab	93d	77c	83c	28b
3000	83f	53de	63d	43c	100d	93d	93c	68d
LSD (P<0.01) $_{ChemTrt*var}$		16				19		

Dry matter at flowering: At Rupanyup, there was no significant reduction in dry matter of all the genotypes from application of up to 3600 gai/ha of simazine (Table 2). While PBA Jumbo, PBA Jumbo 2 and SP1333 had no significant dry matter reduction from application of 765 gai/ha of diuron, PBA Hurricane XT incurred a 22 % reduction (Table 2). The higher rates of diuron caused significant dry matter reduction in all the genotypes except SP1333, which showed greater tolerance to up to 1530 gai/ha of diuron and produced dry matter yield equivalent to the nil treatment. Unlike the other genotypes, SP1333 did not have dry matter reduction from application of 210 gai/ha of metribuzin at Rupanyup (Table 2). At Curyo, all the herbicide treatments except 750 gai/ha of terbuthylazine significantly reduced dry matter (Table 2). All genotypes had severe dry matter loss from application of higher rates of metribuzin and terbuthylazine, ranging from 39-100% at Rupanyup and 74-100% at Curyo (Table 2). However, dry matter reductions from the lower rates of metribuzin and higher rates of terbuthylazine were significantly less in SP1333 than in PBA Hurricane XT, PBA Jumbo and Jumbo 2.

Table 2. Effect of post-sowing pre-emergence application of various rates of Group C herbicides on dry matter yield at flowering (t/ha) of lentil genotypes at Rupanyup and Curyo, Victoria in 2017.

Active ingredient (g/ha)	Rupanyup				Curyo			
	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333
Nil	4.14a	3.72ab	4.31ab	3.52ab	2.93	3.15	2.66	2.17
Diuron								
765	3.25b	4.33a	3.82b	3.21ab				
1530	0.99de	2.13cd	1.17de	2.75b				
3060	1.66cd	2.30cd	1.28d	2.24b				
Metribuzin								
210	2.35c	2.50bc	2.72c	3.35ab	1.36	1.80	1.18	1.90
420	1.28de	0.55e	0.00f	1.27c	0.00	0.00	0.00	1.18
840	0.00f	0.00e	0.00f	0.00	0.00	0.00	0.00	0.00
Simazine								
900	3.70ab	4.03a	4.75a	3.29ab				
1800	3.65ab	4.14a	3.82b	3.16ab				
3600	3.95ab	3.80ab	3.51bc	3.66a				
Terbuthylazine								
750	1.93c	3.18b	2.87c	3.01ab	2.07	2.69	2.57	2.31
1500	0.80ef	1.51d	1.48d	2.15b	0.48	0.66	0.47	1.25
3000	0.00f	0.35e	0.37ef	1.02c	0.00	0.35	0.15	0.29
LSD (P<0.01) $_{ChemTrt*var}$		0.83				ns		

***Grain yield*:** At Rupanyup, all genotypes showed tolerance to application of 765 gai/ha of diuron and up to 3600 gai/ha of simazine and produced grain yield equivalent to their respective nil treatment (Table 3). At the higher rates of diuron, SP1333 had no significant yield loss, while PBA Hurricane XT, PBA Jumbo and PBA Jumbo 2 incurred 39-62% yield loss (Table 3). Yield losses from application of metribuzin and terbuthylazine increased with rates and were generally higher at Curyo than Rupanyup. When metribuzin was applied at 210 gai/ha, SP1333 and PBA Jumbo 2 did not have significant yield loss, while PBA Hurricane XT and PBA Jumbo had 28-35% yield loss at both sites. The highest rate of metribuzin caused complete crop failure in all the genotypes. Terbuthylazine applied at the lowest rate caused significant yield loss in only PBA Hurricane XT at Rupanyup (Table 3). The higher rates of terbuthylazine caused 58-100% yield loss in PBA Hurricane XT, PBA Jumbo and PBA Jumbo 2 (Table 3). In contrast, SP1333 showed improved tolerance and incurred no significant yield loss from application of up to 1500 gai/ha of terbuthylazine (Table 3). However, SP1333 had 23-36% less grain yield than the commercial cultivars in the nil treatment at Rupanyup.

Conclusion

All genotypes did not show sensitivity to 765 gai/ha of diuron and up to 3600 gai/ha of simazine and produced grain yield equivalent to their respective nil treatment. Application of higher rates of metribuzin

and terbuthylazine caused significant injury and yield losses of up to 100%. The herbicide injuries and subsequent yield losses were higher in the lighter sandy soil at Curyo than on the black cracking clay soil at Rupanyup. The differences in sensitivity to the Group C herbicides between PBA Hurricane XT, PBA Jumbo and PBA Jumbo2 were minimal although PBA Hurricane XT appeared to be more sensitive to terbuthylazine at Rupanyup. In contrast, SP1333 showed greater tolerance to up to 3060 gai/ha of diuron, 210 gai/ha of metribuzin and 1500 gai/ha of terbuthylazine, providing opportunity for breeding programs to develop varieties with partial tolerance to PSPE application of photosynthesis-inhibiting herbicides.

Table 3. Effect of post-sowing pre-emergent application of various rates of group C herbicides on the grain yield (t/ha) of lentil genotypes at Rupanyup and Curyo, Victoria in 2017.

Active ingredient (g/ha)	Rupanyup				Curyo			
	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333	PBA Hurricane XT	PBA Jumbo	PBA Jumbo2	SP1333
Nil	3.56a	3.01ab	3.60ab	2.31a	1.51a	1.93a	1.67a	1.46a
Diuron								
765	3.38ab	3.31a	3.76a	1.76ab				
1530	1.37c	1.85bc	1.51c	1.49ab				
3060	1.93bc	1.47c	1.55c	1.45ab				
Metribuzin								
210	2.58b	2.06bc	2.76b	1.77a	1.09a	1.26b	1.52a	1.21ab
420	1.55c	0.55de	0.00d	1.53ab	0.00b	0.00c	0.00c	0.75b
840	0.00d	0.00e	0.00d	0.00c	0.00b	0.00c	0.00c	0.00c
Simazine								
900	3.66a	2.56ab	2.82b	2.30a				
1800	3.12ab	3.24a	3.67ab	1.99a				
3600	2.97ab	2.36b	2.90ab	2.09a				
Terbuthylazine								
750	1.96bc	2.82ab	2.87b	2.06a	1.28a	1.64ab	1.67a	1.45a
1500	1.13c	1.23cd	1.50c	1.69ab	0.27b	0.46c	0.52b	0.98ab
3000	0.00d	0.40e	0.29d	0.90b	0.00b	0.46c	0.17bc	0.18c
LSD (P<0.01) ChemTrt*var		0.87				0.51		

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