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Selective weed control in white oat cultivars with als-inhibiting herbicides*

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Abstract: Background: The limited number of selective herbicides for white oat *(Avena sativa* L.) cultivation makes it managing weeds a challenge. Currently, few herbicide options are available for selective weed control in winter crops. Previous studies have indicated that ALS-inhibiting herbicides could be potential alternatives, so studies were conducted.

Objective: To characterize the tolerance level of white oat cultivars to ALS-inhibiting herbicides and to evaluate the level of weed control by applying penoxsulam and bispyribac-sodium.

Methods: Tolerance (%) was determined for white oat cultivars UFRGS 14, URS Guará, URS Guria, UFRGS 18, and URS Taura for imazethapyr, iodosulfuron, penoxsulam, and bispyribac-sodium dose-response. Also, the control efficiency of different doses of penoxsulam and bispyribac-sodium was determined on weed species of white oat, namely crabgrass *(Digitaria horizontalis)*, siberian motherwort *(Leonurus sibiricus)*, italian ryegrass (*Lolium multiflorum*), and wild radish (*Raphanus raphanistrum*).

Results: Imazethapyr and bispyribac-sodium were the least selective herbicides, whereas iodosulfuron had intermediate selectivity, and penoxsulam was the most selective for the white oat cultivars tested, with average control of 100, 72, 62.7 and 40%, respectively. Overall, bispyribac-sodium had a higher level of weed control (77.1%) than penoxsulam (62%). Label doses of penoxsulam and bispyribac-sodium resulted in low control levels of crabgrass.

Conclusions: All doses of bispyribac-sodium effectively control wild radish and italian ryegrass. The recommended dose of penoxsulam was selective for some cultivars of white oat and effectively controlled italian ryegrass and wild radish.

Keywords: *Avena sativa L.; acetolactate synthase; selectivity; triazolopyrimidine; pyrimidinylthiobenzoates*

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1. Introduction

White oat *(Avena sativa* L.) is a winter crop of great importance in Brazil southern region (Silva et al., 2002). It is used for grain production, as forage, cover crop, and in crop rotation systems (Cantos et al., 2011). Crop productivity is influenced by several factors, including the presence of weeds, which reduce grain productivity, hamper harvesting, and decrease quality of the final product (Nunes et al., 2007). Weed infestation varies depending on the cultivar used, weed species and population density, as well as environmental conditions, management strategies, and the coexistence period (Oliveira Jr. et al., 2011). In Brazil, several weed species occur in white oat and other winter crops (Agostinetto et al., 2015). For example, italian ryegrass (*Lolium rigidum* L.), hemp-nettle (*Galeopsis tetrahit* L.), and wheat (*Triticum aestivum* L.) reduced oat productivity by up to 14%, 50%, and 41%, respectively (Lemerle et al., 1995; Legere, Deschenes, 1991; Zerner et al., 2008).

Weed infestation must be controlled to obtain high yields; however, control must not cause significant damage to the crop. Selectivity is defined as the level of differential toxic action of an herbicide on several plants when applied at the same rate and under the same environmental conditions (Oliveira Jr., Constantin, 2001; Oliveira Jr., Inoue, 2011). The tolerance of a given plant to the herbicide is one of the factors that determine its selectivity (Mahan et al., 2006). Studies on crop tolerance to herbicides that inhibit acetolactate synthase (ALS) have been conducted on several species, such as white oat, rice, tomato, maize, wheat, rapeseed, and sunflower (Queiroz et al., 2017; Shoba et al., 2017; Mohseni-Moghadam, Doohan, 2017; Tan et al., 2005). The mechanisms of plant tolerance to herbicides can be related to target-site (Cruz-Hipolito et al., 2013) or non-target-site (Beckie et al., 2012). Among the characteristics of the plants responsible for herbicide tolerance in plants, the herbicide metabolism stands out, which is the ability to decompose the herbicide molecule, making it inactive in the plant (Délye, 2013). The plant metabolization of the herbicide occurs mainly due to the presence of enzymes of the cytochrome P450 (monooxygenases) and glutathione-s-transferase (GST) groups, responsible for the oxidation and conjugation reactions of the herbicide,

[1] Extracted from the first author's doctoral thesis.

respectively (Hatzios, Burgos, 2004; Scarponi et al., 2006). To increase selectivity, some herbicides are sprayed in association with safeners, which are bioactive compounds that accentuate the degradation pathways of herbicides, specifically in crops (Duhoux et al., 2017).

ALS-inhibiting herbicides are widely used for weed control in many different crops due to their high selectivity, among other factors (Vargas et al., 2001). In Brazil, few herbicide options currently are available for selective weed control in winter crops. Due to a lack of information, some farmers may misuse herbicides and consequently damage the crop species (Nunes et al., 2007). Crop tolerance to herbicides studies help to promote their safe application. Beyond that, allow the expansion of herbicide alternatives and elucidate action mechanisms to be used in weed control. Therefore, the objectives of this study were to characterize white oat cultivars tolerance level for ALS-inhibiting herbicides and evaluate weed control level by application of penoxsulam and bispyribac-sodium.

2. Material and methods

2.1 Tolerance of white oat cultivars to four chemical groups of ALS-inhibiting herbicides

Two greenhouse experiments were conducted in a completely randomized design with four replicates. The first trial was investigated the tolerance of white oat cultivars to ALS-inhibiting herbicides, while in the second trial was analyzed the efficiency of weed control by penoxsulam and bispyribac-sodium.

The first trial was tri-factorial, with factor A consisting of five white oat cultivars (UFRGS 14, URS Guará, URS Guria, UFRGS 18, and URS Taura). Factor B consisted of the ALS-inhibiting herbicides imazethapyr, iodosulfuron, penoxsulam, and bispyribac-sodium, which, respectively, belong to the imidazolinone, sulfonylurea, triazolopyrimidine, and pyrimidinylthiobenzoate chemical groups. The factor C consisted of five doses of the herbicides (0x, 1x, 2x, 4x, and 6x, where x represents the label dose). The corresponding concentrations were 0, 100, 200, 400, and 600 g a.i. ha^{-1} of imazethapyr; 0, 5, 10, 20, and 30 g a.i. ha^{-1} of iodosulfuron; 0, 60, 120, 240, and 360 g a.i. ha^{-1} of penoxsulam; 0, 50, 100, 200, and 300 g a.i. ha^{-1} of bispyribac-sodium.

The herbicides were sprayed on the plants when they were at the 4-5 leaf stage. No adjuvant was added to imazethapyr, following the manufacturer's instructions. Meanwhile, 0.5% mineral oil was added to bispyribac-sodium, an adhesive spreader with 0.3% sodium lauryl ether sulfate was added to iodosulfuron, and an adjuvant with 1 L ha^{-1} ethoxylated alkyl ester of phosphoric acid was added to penoxsulam. Treatments were applied using a CO_2 pressurized sprayer at constant pressure, with three 110° 02 flat fan nozzles, calibrated to deliver 200 L ha^{-1}.

2.2 Weed control by penoxsulam and bispyribac-sodium

The second trial was also tri-factorial. Factor A consisted of the ALS-inhibiting herbicides penoxsulam and bispyribac-sodium. Factor B included the weed species crabgrass (*Digitaria horizontalis* Willd.), siberian motherwort (*Leonurus sibiricus* L), italian ryegrass (*Lolium multiflorum L.)*, and wild radish (*Raphanus raphanistrum* L).The factor C was represented by eight dose ratios of the herbicides (0x, 0.125x, 0.25x, 0.5x, 1x, 2x, 4x, and 6x, where x represents the label dose). The corresponding concentrations were 0, 7.5, 15, 30, 60, 120, 240, and 360 g a.i. ha^{-1} of penoxsulam, and 0, 6.25, 12.5, 25, 50, 100, 200, and 300 g a.i. ha^{-1} of bispyribac-sodium. The herbicides were sprayed on plants at the 3-4 leaf stage. The application technology of the herbicides followed the same conditions as the first trial. Both experiments were conducted in pots of five dm^3 composed of soil, containing one plant per pot.

Assessments of visual control were performed for both trials on the 28th day after application (DAA) of the herbicides, using a visual scale adapted from Frans et al. (1986), in which 0% represents the absence of control (100% tolerance) and 100% represents plant death (0% tolerance). In this period, aerial part of the plants were harvested at soil level. Subsequently, the samples were packed in a dryer with forced air circulation at a temperature of 60°C and kept until reached a constant mass, at which point the mass of the dry aerial part (DMAP) was determined. The DMAP of each sample was expressed as a percentage of the weight of the control, in which no herbicide was applied.

An analysis of variance using the F test ($p<0.05$) was performed on the data. Nonlinear models were used to adjust the regressions between dependent variables and herbicide concentrations using the three-parameter logistic model (Equation 1) in SigmaPlot® version 10.0 (Systat Software Inc, 2006), as follows:

$$y = a / (1+(x / x_0)^b) \quad \text{(Equation 1)}$$

Where: y= dependent variable; a = maximum asymptote; x = concentration of the herbicide; x_0= concentration that provides 50% of control (C_{50}) or reduction of the dry mass (GR_{50}); b = curve slope.

The standard error of the mean was calculated as the quotient of the standard deviation and the square root of the sample size. The parameters C_{50} and GR_{50} represent the dose necessary to provide a 50% control level and a 50% DMAP reduction, respectively. Tolerance factors (TF) were calculated as the quotient of the C_{50} values of the most tolerant cultivar and the most herbicide-sensitive cultivar.

3. Results and discussion

3.1 Tolerance of white oat cultivars to four chemical groups of ALS-inhibiting herbicides

The cultivars responded differently to the herbicides evaluated. On the 28th DAA, there was a reduction

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in tolerance (%) with increased doses of herbicides (Figure 1). At the 1x dose (label dose), imazethapyr showed no selectivity to all cultivars (Figure 1 a), while bispyribac-sodium was less selective in relation to the URS Guria cultivar (Figure 1 c). The maximum tolerance reached at the 1x dose was 73.3%, when applying iodosulfuron to the URS Guará cultivar (Figure 1 b). At the highest tested dose of herbicides (6x), the lowest tolerance was 0%, a value obtained by the UFRGS 14 cultivar with penoxsulam, as well as all cultivars tested with imazethapyr, bispyribac-sodium, and iodosulfuron, except for the cultivar URS Guará with iodosulfuron (Figure 1 a, b, c, and d).

Penoxsulam presented the highest selectivity across all cultivars, followed by iodosulfuron, bispyribac-sodium, and imazethapyr. URS Guará showed the highest tolerance to herbicides among all tested cultivars, followed by URS Taura, UFRGS 18, URS Guria, and UFRGS 14 (Figure 1 a, b, c, and d).

C_{50} and TF values on the 28th DAA indicated no difference in tolerance level between cultivars with imazethapyr since all cultivars were fully suppressed at all herbicide levels. For iodosulfuron, penoxsulam, and bispyribac-sodium, the lowest C_{50} values were 3.55 (with URS Guria), 89.40 (with UFRGS 14), and 10.00 g a.i. ha^{-1} (with URS Guria), respectively. Overall, the TF values obtained were low. The highest significant TF value was 11.6, achieved by applying bispyribac-sodium to URS Guará (Table 1). Although bispyribac-sodium had the second-lowest average TF value, it had the highest range of TF values (Table 1), which may be due to the greater variation of tolerance among cultivars.

Increased herbicide doses inhibited the growth of all five cultivars, and consequently reduced their relative DMAP values (Figure 2). Penoxsulam was the one that least inhibited plant growth in all cultivars, followed by iodosulfuron, bispyribac-sodium, and imazethapyr. Imazethapyr resulted in the lowest tolerance of all tested

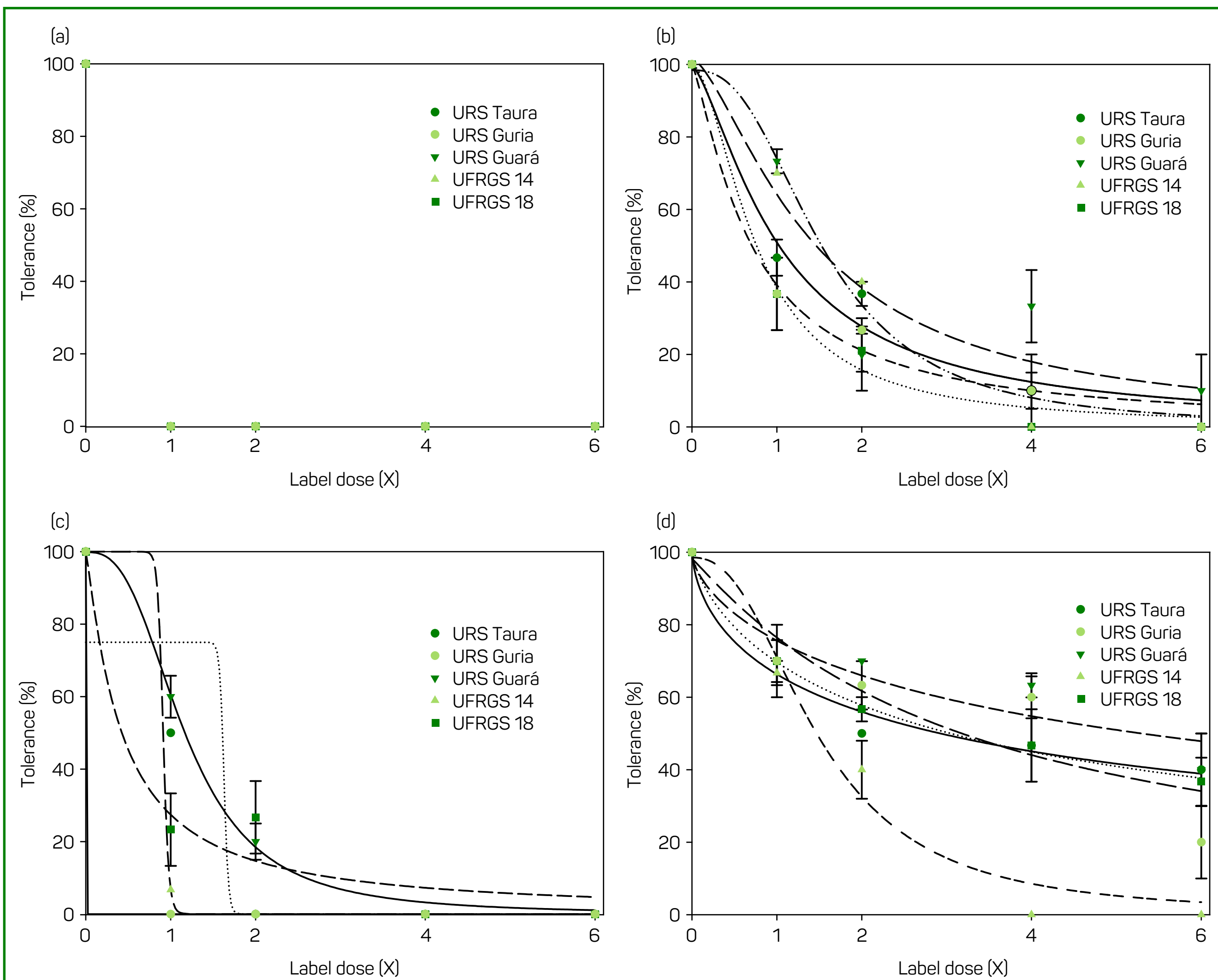

Figure 1 - Tolerance (%) of the white oat cultivars URS Taura, URS Guria, URS Guará, UFRGS 14, and UFRGS 18 on the 28th day after application (a) imazethapyr, (b) iodosulfuron, (c) bispyribac-sodium, and (d) penoxsulam. Vertical bars represent the standard error of the average for each treatment, n=4

Table 1 - Estimates of the parameters of the equation [1] describing the effect of doses (g a.i. ha^{-1}) of imazethapyr, iodosulfuron, bispyribac-sodium and penoxsulam on the tolerance of plants of five white oat cultivars (UFRGS 14, URS Guará, URS Taura, URS Guria, and UFRGS 18) on the 28th day after application

	Cultivars	Parameters[1]				
		a	*b*	*X0*(C_{50}**)	R^2	TF
Imazethapyr	UFRGS 14	100*	1.52 ns	<0.001 ns	0.99ns	1.00
	URS Guará	100*	1.52 ns	<0.001 ns	0.99ns	1.00
	URS Taura	100*	1.52 ns	<0.001 ns	0.99ns	1.00
	URS Guria	100*	1.52 ns	<0.001 ns	0.99ns	1.00
	UFRGS 18	100*	1.52 ns	<0.001 ns	0.99ns	1.00
Iodosulfuron	UFRGS 14	100*	2.55 ns	7.70*	0.98*	2.17
	URS Guará	100*	1.50 ns	7.15 ns	0.94ns	2.01
	URS Taura	100*	1.44 ns	5.15 ns	0.98*	1.45
	URS Guria	100*	1.27 ns	3.55 ns	0.99*	-
	UFRGS 18	100*	1.74 ns	3.80*	0.99*	1.07
Bispyribac-sodium	UFRGS 14	100*	27.88*	91.00*	0.99*	9.10
	URS Guará	100*	2.76*	116.00*	0.99*	11.60
	URS Taura	100 ns	63.95 ns	163.00 ns	0.92ns	16.30
	URS Guria	100 ns	1.52 ns	10.00 ns	0.98ns	-
	UFRGS 18	100*	1.14 ns	43.00 ns	0.98ns	4.30
Penoxsulam	UFRGS 14	100*	2.38 ns	89.40*	0.99*	-
	URS Guará	100*	0.69 ns	324.00 ns	0.95ns	3.62
	URS Taura	100*	0.63*	174.60*	0.99*	1.95
	URS Guria	100*	1.06 ns	183.00 ns	0.93ns	2.05
	UFRGS 18	100*	0.75*	197.40*	0.99*	2.21

[1] Equation of the three-parameter logistic model $Y= a/(1+(x/X0)^b)$: a= maximum asymptote, b= curve slope. **C_{50}= Dose (g a.i. ha^{-1}) providing 50% control. TF (Tolerance Factor) = C_{50} tolerant/ C_{50} susceptible.
*Significance by the t-test at 5% probability of error; ns non-significant.

cultivars (Figures 1 and 2). URS Guará showed the lowest DMAP reductions following herbicide application, followed by UFRGS 14, UFRGS 18, URS Taura, and URS Guria (Figure 2 a, b, c and d).

The GR_{50} values of the DMAP of URS Guria were the lowest for all herbicides, indicating its low tolerance (Table 2). UFRGS 14 had the highest GR_{50} value for imazethapyr and iodosulfuron, while URS Guará and UFRGS 18 had the highest GR_{50} values for penoxsulam and bispyribac-sodium, respectively. Imazethapyr had the lowest GR_{50} values, and penoxsulam had the highest GR_{50} for all tested cultivars, reflecting their higher tolerance to this herbicide (Table 2). Previous studies also showed that imazethapyr had low selectivity for white oats (Hartwig et al., 2008; Dalazen et al., 2015).

The results of the visual evaluation and DMAP confirmed the variable levels of tolerance between cultivars regardless of the herbicide evaluated. Furthermore, there was a difference in the tolerance of each cultivar for the different herbicides, suggesting an interaction between the factors. However, in some cases, tolerance rankings were identical for two herbicides: the UFRGS 14 cultivar, for example, exhibited the lowest tolerance to both penoxsulam and iodosulfuron. The genetic variability of cultivars, the tolerance mechanism and the herbicide molecule can result in different levels of tolerance to herbicides (Hartwig et al., 2008; Merotto Jr. et al., 2000).

White oat cultivars showed different tolerance levels to iodosulfuron, suggesting that the mechanism involved in this tolerance is the metabolization of the herbicide (Queiroz et al., 2017). Some studies showed low tolerance levels of oat cultivars to ALS-inhibiting herbicides (Macrae et al., 2007), while others detected moderate to high tolerance to some herbicides of this

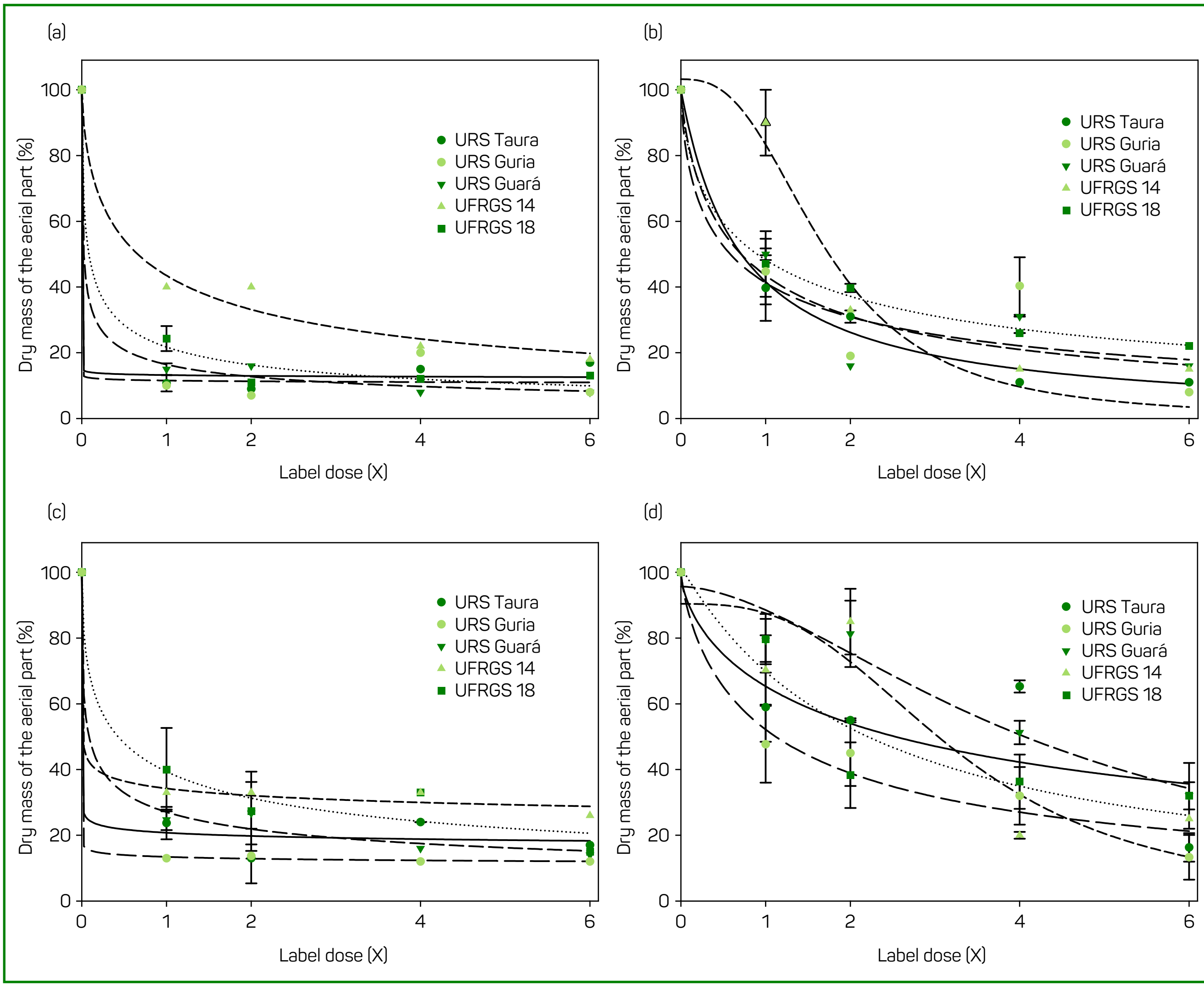

Figure 2 - Dry mass of the aerial part (%) due to the application of the herbicides (a) imazethapyr, (b) iodosulfuron, (c) bispyribac-sodium, and (d) penoxsulam on the white oat cultivars URS Taura, URS Guria, URS Guará, UFRGS 14, and UFRGS 18. Vertical bars represent the standard error of the average for each treatment, n=4

same action mechanism in oat cultivars (Cargnin et al., 2006; Hartwig et al., 2008).

Cultivated plants show great variability in the degree of tolerance to herbicides. Tolerance occurs according to morphological, physiological or biochemical characteristics responsible for the level of susceptibility of a species, compared to other species or cultivars. This may be related to leaf retention, absorption and / or translocation and differential metabolization of the herbicides and also by modification in the target site of action (Oliveira Jr., Inoue, 2011). The variability in the level of tolerance to different herbicides in cultivars is due to the fact that it is influenced by characteristics related to the herbicides, the environment and the existing tolerance mechanisms in the plant (Azania, Azania, 2014).

The herbicide doses can influence levels of selectivity in a crop. High doses above label recommendation may reduce the tolerance of the crop by increasing the product concentration in the plant, preventing its total degradation or metabolization (Kong et al., 2009; Barros et al., 2016). This effect was confirmed in this study, in which all tested cultivars showed reduced tolerance following doses of herbicides increased up to six times the label dose. However, some cultivars showed a lower degree of reduction in tolerance than others.

Cross-resistance to the different chemical groups of ALS-inhibiting herbicides due to site-specific mutations has been observed in cultures (Webster, Masson, 2001). The pattern of cross-tolerance to herbicides may be obscured by the co-occurrence of action mechanisms of tolerance outside the target site in the population, as in the case of metabolization (Beckie et al., 2012). The selectivity of penoxsulam observed in this study may benefit the control of weeds in oat culture; however, further studies related to the cultivar tolerance mechanism are necessary

Table 2 - Estimates of the parameters of the equation[1] describing the effect of doses (g a.i. ha^{-1}) of herbicides imazethapyr, iodosulfuron, bispyribac-sodium and penoxsulam on the dry mass of the aerial part of plants of five white oat cultivars (UFRGS 14, URS Guará, URS Taura, URS Guria, and UFRGS 18)

	Cultivars	Parameters[1]				
		a	*b*	*X0* (GR_{50}**)	R^2	TF
Imazethapyr	UFRGS 14	100*	0.63 ns	66.00 ns	0.99ns	660000
	UFRGS 18	100*	0.51 ns	8.00 ns	0.99ns	80000
	URS Guará	100*	0.43 ns	2.00 ns	0.99ns	2000
	URS Taura	100*	0.03 ns	<0.001 ns	0.99ns	10
	URS Guria	100*	0.03 ns	<0.0001ns	0.99ns	-
Iodosulfuron	UFRGS 14	103*	1.78 ns	9.10 ns	0.92ns	3.14
	UFRGS 18	100*	0.66*	4.50*	0.99*	1.55
	URS Guará	100*	0.77 ns	3.50 ns	0.96ns	1.21
	URS Taura	100*	1.00*	3.55*	0.99*	1.22
	URS Guria	100*	0.65 ns	2.90 ns	0.94ns	-
Bispyribac-sodium	UFRGS 14	100*	0.14 ns	0.94 ns	0.99ns	940
	UFRGS 18	100*	0.51 ns	42.00 ns	0.99ns	42000
	URS Guará	100*	0.40 ns	9.00 ns	0.99ns	9000
	URS Taura	100*	0.09 ns	0.25 ns	0.99ns	250
	URS Guria	100*	0.07 ns	<0.001 ns	0.99ns	-
Penoxsulam	UFRGS 14	91*	2.89 ns	196.20 ns	0.92ns	2.89
	UFRGS 18	101*	1.04 ns	129.00 ns	0.95ns	1.90
	URS Guará	96*	1.73 ns	256.20*	0.98*	3,77
	URS Taura	100*	0.69 ns	155.40 ns	0.86ns	2.29
	URS Guria	100*	0.78 ns	67.80 ns	0.98ns	-

[1]Equation of the three-parameter logistic model $Y= a/(1+(x/X0)^b)$: a= Maximum asymptote, b= Curve slope. **GR_{50}= Dose (g a.i. ha^{-1}) providing 50% dry mass reduction.

TF (Tolerance Factor) = C_{50} tolerant/ C_{50} susceptible.

*Significance by the t-test at 5% probability of error; ns non-significant

to verify its phytotoxic effect and, consequently, to confirm its effectiveness.

3.2 Weed control by penoxsulam and bispyribac-sodium

Increasing the dose of penoxsulam and bispyribac-sodium increased the levels of weed control. The application of bispyribac-sodium resulted in more effective control of all evaluated weeds compared to penoxsulam (Figure 3 a and b). A full control (100%) was achieved for italian ryegrass at doses higher than 0.5x penoxsulam and wild radish at penoxsulam doses higher than 2x.

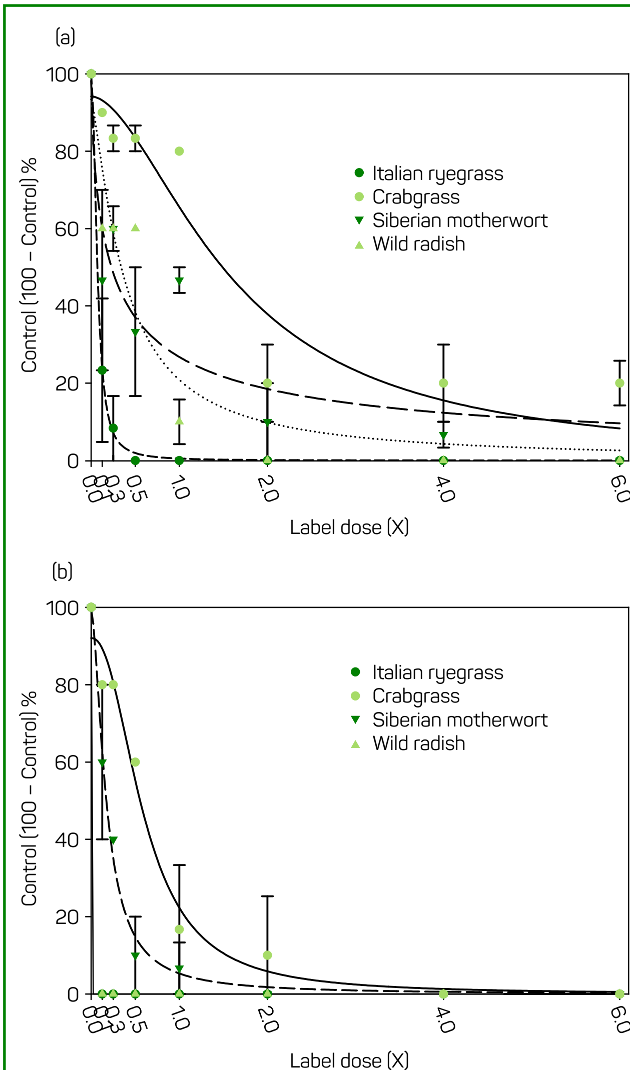

Figure 3 - Control (%) of weed species on the 28th day after application of the herbicides a) penoxsulam and b) bispyribac-sodium. Vertical bars represent the standard error of the average for each treatment, n=4.

The control levels of crabgrass with penoxsulam were the lowest among the evaluated species at all the tested doses (Figure 3 a). Wild radish and italian ryegrass showed 100% control at all tested doses of bispyribac-sodium. The 1x dose of this herbicide provided efficient control (over 80%), and the doses over 2x resulted in full control (100%) of the weeds (Figure 3 b).

C_{50} values were lower in bispyribac-sodium compared to penoxsulam for all weed species (Table 3). The lowest C_{50} value for penoxsulam was obtained with italian ryegrass, while the lowest C_{50} values for bispyribac-sodium were obtained with italian ryegrass and wild radish (Table 3).

For all weeds tested, there was a reduction of the DMAP in comparison to the control when the doses of penoxsulam and bispyribac-sodium were increased. Bispyribac-sodium caused a higher inhibition of plant development than

Table 3 - Estimates of the parameters of the equation[1] describing the effect of doses of herbicides penoxsulam and bispyribac-sodium on the control and dry mass of the aerial part of weed species (italian ryegrass, crabgrass, siberian motherwort, and wild radish) on the 28th day after application

Herbicides	Weed species	Parameters[1]			
Control (%)					
		a	*b*	*X0(C_{50}**)*	R^2
Penoxsulam	Italian ryegrass	100*	1.99*	4.20*	0.99*
	Crabgrass	95*	1.77*	96.00*	0.95*
	Siberian motherwort	98*	0.69*	14.40 ns	0.94*
	Wild radish	93*	1.29*	22.80*	0.95*
Bispyribac-sodium	Italian ryegrass	100 ns	1.11 ns	<0.0001 ns	0.99ns
	Crabgrass	95*	1.73*	29.50*	0.99*
	Siberian motherwort	100*	34.8*	6.50*	0.99*
	Wild radish	100 ns	1.11 ns	<0.0001 ns	0.99 ns
Dry mass of the aerial part (%)					
		a	*b*	*X0(GR_{50}**)*	R^2
Penoxsulam	Italian ryegrass	100*	1.69*	6.60*	0.99*
	Crabgrass	107*	0.94*	174.00*	0.86*
	Siberian motherwort	100*	0.62*	4.20*	0.94*
	Wild radish	93*	1.27*	22.20*	0.95*
Bispyribac-sodium	Italian ryegrass	100 ns	1.11 ns	<0.0001 ns	0.99ns
	Crabgrass	96*	1.34*	77.50*	0.91*
	Siberian motherwort	100*	1.05*	5.00*	0.99*
	Wild radish	100 ns	1.11 ns	<0.0001 ns	0.99ns

[1]Equation of the three-parameter logistic model $Y= a/(1+(x/X_0)^b)$: a= Maximum asymptote, b= Curve slope. **C_{50} or GR_{50}= Dose (g a.i. ha^{-1}) providing 50% control or providing 50% dry mass reduction.

*Significance by the t-test at 5% probability of error; ns non-signific

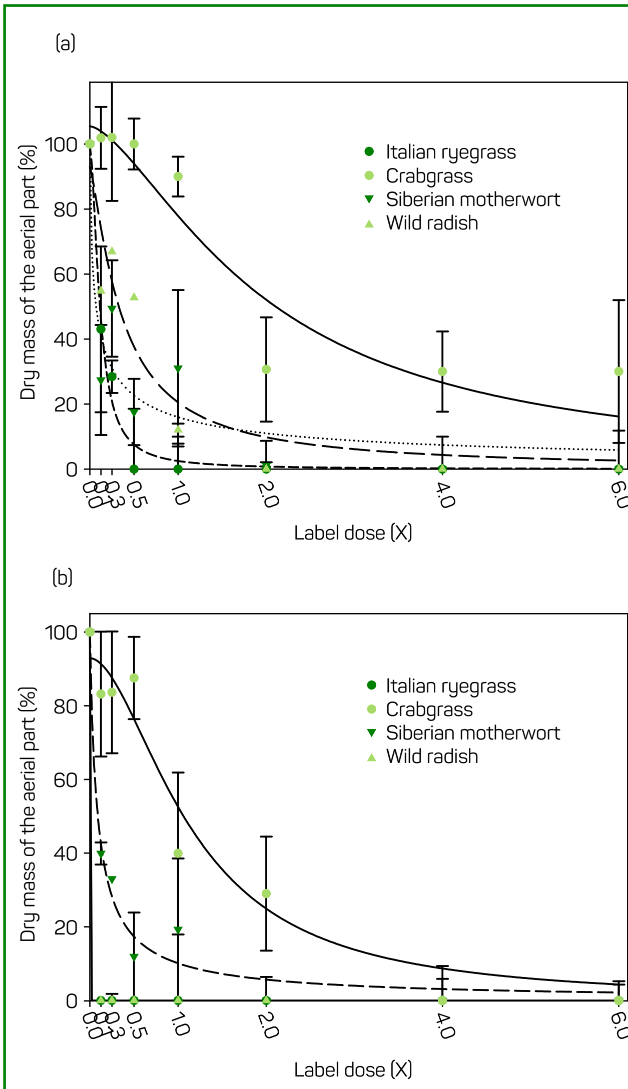

Figure 4 - Dry mass of the aerial part (%) of the weed species italian ryegrass, crabgrass, siberian motherwort, and wild radish due to the application of the herbicides penoxsulam (a) and bispyribac-sodium (b). Vertical bars represent the standard error of the average for each treatment, n = 4

penoxsulam (Figure 4 a and b), as indicated by the lowest GR_{50} values (Table 3). For both herbicides, crabgrass had the highest tolerance (highest GR_{50} value), while italian ryegrass and siberian motherwort had the lowest GR_{50} values for penoxsulam, and italian ryegrass and wild radish had the lowest GR_{50} values for bispyribac-sodium (Table 3).

This study provides important information on the potential to control specific weeds with bispyribac-sodium and penoxsulam. In this study, the use of bispyribac-sodium and penoxsulam in commercial doses of both are justified by the tolerance levels obtained in some cultivars and also by the possibility of controlling weeds important for the cultivation of oats. This would allow the rotation of active ingredients in crops that already use iodosulfuron and metsulfuron in winter crops. For both herbicides, the 1x dose showed the lowest level of phytointoxication in the cultivars tested, however with this dose it was possible to obtain a high level of control for most weeds. However, the use of doses from the commercial bispyribac-sodium showed reduced selectivity for most white oat cultivars tested, being recommended its use with caution in different white oat cultivars. Doses below the label dose provided high levels of control of wild radish and italian ryegrass by bispyribac-sodium and italian ryegrass by penoxsulam. The registered label doses of these herbicides did not fully control siberian motherwort or crabgrass, although the control levels with bispyribac-sodium were much higher than with penoxsulam. Both herbicides stood out for their efficiency in controlling italian ryegrass and wild radish.

Studies determining selectivity and weed control in the field will be of great assistance to confirm these results, which were obtained in assays conducted in a controlled environment. At present, the oat crop has only three herbicides registered for weed control in Brazil, one of which is metsulfuron-methyl, an ALS inhibitor (Ministério da Agricultura, Pecuária e Abastecimento, 2019). Examining the crop's selectivity to other ALS-inhibiting herbicides is essential, as it allows the rotation of chemical groups and potentially increases the spectrum of controlled weeds.

This study detected different tolerance levels between the white oat cultivars and the ALS-inhibiting herbicides tested. Imazethapyr and bispyribac-sodium were the least selective to the cultivars assessed, while iodosulfuron showed intermediate selectivity, and penoxsulam was the most selective herbicide. There was a differentiated response of the weeds to these herbicides. Bispyribac-sodium showed higher control levels than penoxsulam for all weeds. Label doses of penoxsulam and bispyribac-sodium resulted in low control levels for crabgrass. All tested doses of bispyribac-sodium were effective in controlling wild radish and italian ryegrass. The use of the recommended dose of penoxsulam allowed selectivity in some white oat cultivars, like URS Guará, and allowed efficient control of italian ryegrass and wild radish.

Authors' contributions

XE: designed the study and wrote the manuscript. MMT: designed the study and the project; helped to write the manuscript. MCO: designed the project; helped to write the manuscript. RAV: designed the study and the project.

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