AGRONOMY (AGRONOMIA)

Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.16, n.3, e413, 2021
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v16i3a413
Protocol 413 - 06/04/2021 • Approved in 21/05/2021

Chemical control of wild radish and volunteer Enlist™ soybean and selectivity to wheat crop

Juliano Gazola[1], Geovana Facco Barbieri[1]*, Cristiano Piasecki[1], Alcimar Spindola Mazon[1], Dirceu Agostinetto[1]

[1] Universidade Federal de Pelotas, Faculdade de Agronomia Eliseu Maciel, Departamento de Fitossanidade, Pelotas, RS, Brasil. E-mail: julianogazola@hotmail.com; geovanafacco@hotmail.com; c_piasecki@hotmail.com; alcimarmazon@hotmail.com; agostinetto.d@gmail.com

ABSTRACT: The incidence of volunteer Enlist™ soybean in the post-emergence of crops in succession, such as wheat, requires changes in chemical control. Thus, the objective of the work is to evaluate the efficiency of different post-emergence herbicides in the control of volunteer Enlist™ soybean and wild radish and their selectivity to wheat. For this, four experiments were conducted in 2017 and 2018 in field and greenhouse. The treatments tested were pyroxsulam, saflufenacil, pyroxsulam + saflufenacil, pyroxsulam + bentazon, pyroxsulam + metribuzin, saflufenacil + bentazon, and saflufenacil + metribuzin in 2017, and triclopyr, saflufenacil, MCPA, quinclorac, dicamba, pyroxsulam + metribuzin, metribuzin + metsulfuron, pyroxsulam + bentazon and bentazon + metsulfuron in 2018. The variables were the control of wild radish and volunteer Enlist™ soybean phytotoxicity to wheat crop, yield components, and yield total. The association of the herbicides pyroxsulam and saflufenacil is efficient in the management of volunteer soybean Enlist™, showing selectivity to wheat. The isolated application of dicamba and the associations of pyroxsulam with metribuzin and metribuzin with metsulfuron represent alternatives for selective management of volunteer Enlist™ soybean in wheat, in addition to efficiently controlling wild radish in post-emergence.

Key words: *Glycine max*; phytotoxicity; *Raphanus* spp.; *Triticum aestivum* L.

Controle químico de nabo e soja voluntária Enlist™ e seletividade à cultura do trigo

RESUMO: A incidência de soja voluntária Enlist™ na pós-emergência de culturas em sucessão, como o trigo, resultará na necessidade de mudanças no controle químico. Dessa forma, o objetivo do trabalho foi avaliar a eficiência de diferentes herbicidas pós-emergentes no controle de soja voluntária Enlist™ e nabo, e sua seletividade à cultura do trigo. Para isso, foram conduzidos quatro experimentos nos anos de 2017 e 2018, em nível de campo e casa de vegetação. Os tratamentos testados foram: pyroxsulam, saflufenacil, pyroxsulam + saflufenacil, pyroxsulam + bentazon, pyroxsulam + metribuzin, saflufenacil + bentazon e saflufenacil + metribuzin, no ano de 2017 e triclopyr, saflufenacil, MCPA, quinclorac, dicamba, pyroxsulam + metribuzin, metribuzin + metsulfuron, pyroxsulam + bentazon e bentazon + metsulfuron, no ano de 2018. Como variáveis, foi avaliado o controle de nabo e soja voluntária Enlist™, fitotoxicidade à cultura do trigo, os componentes de produtividade e a produtividade total. A associação dos herbicidas pyroxsulam e saflufenacil foi eficiente no manejo de soja voluntária Enlist™, apresentando seletividade à cultura do trigo. A aplicação dicamba isolado e as associações de pyroxsulam com metribuzin e metribuzin com metsulfuron caracterizaram-se como alternativas para manejo seletivo de soja voluntária Enlist™ em trigo, além de controlarem eficientemente o nabo em pós-emergência.

Palavras-chave: *Glycine max*; fitotoxicidade; *Raphanus* spp.; *Triticum aestivum* L.

---

* Geovana Facco Barbieri - E-mail: geovanafacco@hotmail.com (Corresponding author)
Associate Editor: Leandro Galon

Introduction

Wheat (*Triticum aestivum* L.) is the main winter cereal grown in southern Brazil. Its production area is about two thousand hectares (Conab, 2021). In addition to the benefits of soil conservation and nutrient cycling, winter crops such as wheat are an important tool in the integrated management of weeds, enabling changes in the mechanisms of action used in the summer harvest.

Among the factors limiting the expression of the productive potential of wheat is competition with weeds, which negatively affects wheat growth and development and causes yield losses and grain quality (Lamego et al., 2013). In this context, wild radish (Raphanus spp.) stands out due to its highly competitive potential with wheat (Goggin et al., 2016) and the presence of biotypes resistant to herbicides inhibiting the enzyme acetolactate synthase (ALS) (Heap, 2021). In addition, volunteer soybean and corn plants in wheat have caused difficulties in management, with a tendency to intensify problems due to new technologies that confer resistance to herbicides, as is the case of the Enlist^{TM} technology.

The Enlist^{TM} soybean was developed aiming the use of the herbicides 2,4-D, glyphosate, and glufosinate ammonium during pre- and post-emergence, since this soybean presents tolerance to these molecules (Skelton et al., 2017). Although it allows the use of different molecules during the post-emergence, the presence in Enlist^{TM} soybean cultivars of genes that confer resistance to the main molecules used in the management of desiccation of winter coverings results in changes in the chemical control of volunteer incident plants after harvesting in areas of soybean/wheat succession (Zobiole & Kalsing, 2017).

The chemical control of volunteer plants prevents their establishment in agricultural areas, avoiding the loss of yield crop in succession due to competition for resources in the environment (Terasawa et al., 2009). In this sense, volunteer plants may occupy an ecological niche similar as that of the crop and, together with factors such as the density of plants in the area and the period of growing together with the crop, determine the intensity of yield losses. In corn crop, the maximum losses due to competition with high populations of volunteer RR$^{®}$ soybean caused yield losses of 56% (Alms et al., 2016), a percentage of loss similar as that caused by weeds such as *Chenopodium album* (Moechnig et al., 2003) and *Amaranthus retroflexus* in that crop (Knezevic et al., 1994). Volunteer RR$^{®}$ soybean plants in succession areas of soybean/rice resulted in losses of 16% in rice yield, showing the interference of these plants and the need for control (Bond & Walker, 2009).

After the launch of the Enlist^{TM} soybean technology, studies indicating post-emergence herbicides alternative to 2,4-D for application in wheat crop are necessary aiming an efficient control of volunteer Enlist^{TM} soybean and other eudicotyledon weeds without harming the development of the crop. Thus, the objective of the work is to evaluate the efficiency of different post-emergence herbicides in the control of volunteer Enlist^{TM} soybean and wild radish and the selectivity of these herbicides to wheat.

Materials and Methods

This study consists of experiments conducted in the field in the experimental area of the Centro Agropecuário da Palma/UFPel (Experiments I and II) and in a greenhouse at the Centro de Herbologia of the Faculdade de Agronomia Eliseu Maciel/UFPel (Experiments III and IV) in 2017 and 2018.

The Experiment I aimed to evaluate the control of volunteer Enlist^{TM} soybean and selectivity to wheat by applying herbicides. The design was randomized blocks with four replications, in which the experimental units consisted of plots with 4.59 m^2 (1.53 × 3.0 m). The wheat cultivar TBIO Toruk and the discontinued Enlist^{TM} soybean lineage were sown at a density of 150 kg ha^{-1} and five plants m^{-2}, respectively, in a no-tillage system. The basic fertilization was carried out using 450 kg ha^{-1} of the formulation NPK 05-20-20, according to soil analysis and recommendations for crop. For the cover fertilization, 80 kg ha^{-1} of nitrogen were used as urea, fractionated in an application at the beginning of the tillering and another at the beginning of the crop stem elongation.

Table 1 shows the treatments and doses used in the field with the specific adjuvant added to the spray solution when recommended in the package insert (Brazil's Ministry of Agriculture, 2021). The treatments were applied when the plants of volunteer Enlist^{TM} soybean were between the stages V_4 and V_5, and the wheat crop at the stem elongation stage. For the application, a pressurized backpack sprayer with CO_2

Table 1. Treatments and respective doses of herbicides used in experiment I.

Treatments	Commercial product	Dose (g a.i. ha^{-1})	Dose (l/g c.p. ha^{-1})
Weeded check	-	-	-
Untreated check	-	-	-
Pyroxsulam	Tricea®	18	0.4
Saflufenacil	Heat®	98	140
Pyroxsulam + Saflufenacil	Tricea® + Heat®	18 + 98	0.4 + 140
Pyroxsulam + Bentazon	Tricea® + Basagran 600	18 + 720	0.4 +1.2
Pyroxsulam + Metribuzin	Tricea® +Sencor® 480	18 + 144	0.4 + 0.3
Saflufenacil + Bentazon	Heat® + Basagran® 600	98 + 720	140 +1.2
Saflufenacil + Metribuzin	Heat® + Sencor® 480	98 + 144	140 + 0.3

was used, equipped with fan tips 110.015 and a spray volume equivalent to 120 L ha^{-1}.

The control of weeds that were not the target of this experiment occurred through the application of clodinafop-propargyl (0.25 L ha^{-1}), plus mineral oil Assist$^{®}$ (0.5%), in addition to complementary weeding. Weeding was carried out weekly to maintain the weeded check. In addition, during the crop development, four applications of fungicides were carried out following the doses recommended for the crop.

The variables analyzed were phytotoxicity to wheat crop and volunteer Enlist$^{\text{TM}}$ soybean control at 7, 14, 21, and 28 days after application of treatments (DAT). Phytotoxicity and control were assessed using a visual scale from 0 to 100%, where 0 averages no injury and 100% complete plant death. The other parameters evaluated were the number of ears m^{-2} (NE), the number of grain spikelet^{-1} (NGS), the number of spikelets ear^{-1} (NSE), hectoliter weight (HW), and grain yield wheat (kg ha^{-1}). To determine of NE, the number of ears in a square with an area of 0.25 m^{2} was counted. The NGS and NSE were determined by collecting ten ears per experimental unit and later counting the number of grains and spikelets. The determination of HW followed the procedure described in the Seed Analysis Rules (Brazil, 2009). The evaluation of wheat grain yield was by harvesting an area of 2.38 m^{2} per experimental unit, with the final weight of grains corrected to 13% moisture and estimated in kg ha^{-1}.

The experiment II aimed to evaluate the selectivity to wheat crop. The design was randomized blocks with four replications, in which the experimental units consisted of plots with 7.65 m^{2} (1.53 × 5.0 m). The wheat cultivar TBIO Toruk was sown at a density of 170 kg ha^{-1}, and the base and cover fertilization were carried out as described in experiment I. Experiments III and IV were carried out in a greenhouse due to the low population of wild radish and volunteer Enlist$^{\text{TM}}$ soybean in the conduction area of experiment II. This experiment was completely randomized with four replications. Each experimental unit consisted of plastic pots with a volumetric capacity of 1.75 L filled with soil and containing three wild radish plants (experiment III) and four soybean plants (experiment IV).

Table 2 shows the treatments and doses used in experiments II, III, and IV. In experiment II, the treatments were applied when the wheat was at the elongation stage and weeding was carried out weekly to maintain a weeded check. In experiments III and IV, the treatments were applied when wild radish plants had four to six leaves and the soybean plants were between the stages V$_4$ and V$_5$, respectively. The treatments were applied as described for experiment I.

The variables analyzed in experiment II were phytotoxicity of herbicides to the wheat at 10, 20, and 30 DAT, in addition to yield components and wheat total yield, according to the methodology described in experiment I. The weight of a thousand seeds (WTS) was quantified by weighing eight subsamples of one hundred grains per plot and the values were adjusted to 13% humidity, according to the Seed Analysis Rules (Brazil, 2009). In experiments III and IV, the control of wild radish and volunteer Enlist$^{\text{TM}}$ soybean at 7, 14, 21, and 28 DAT was evaluated using the visual scale, as described for experiment I.

The data were analyzed for normality (Shapiro Wilk test) and homoscedasticity (Hartley test) and later subjected to analysis of variance ($p \leq 0.05$). If significant, the averages were compared using the Duncan test ($p \leq 0.05$). All analyses were performed using the software R.

Results and Discussion

For experiment I, the analysis of variance showed significance for the variables phytotoxicity and control of volunteer Enlist$^{\text{TM}}$ soybean on all evaluation dates and for the yield components number of spikelets^{-1} (NSE), number of ears m^{-2} (NE), and grain yield (Tables 3, 4, and 5). For experiments II, III, and IV, there was significance for control of wild radish and volunteer Enlist$^{\text{TM}}$ soybean and phytotoxicity on all evaluation dates, in addition to the yield components hectoliter weight (HW), weight of a thousand seeds (WTS), and grain yield (Tables 6 to 9). It was not necessary to perform data transformation for the analyzed variables.

Regarding the control of volunteer Enlist$^{\text{TM}}$ soybean in the experiment conducted in 2017, in general treatments involving the herbicide saflufenacil alone and in mixture with pyroxsulam, bentazon and metribuzin promoted a control above 80% in all evaluations, not differing from the weeded check at 7 and 21 DAT (Table 3). The mixture of pyroxsulam

Table 2. Treatments and respective doses of herbicides used in experiment II.

Treatments	Commercial product	Dose (g a.i. ha^{-1})	Dose (l/g c.p. ha^{-1})
Weeded check	-	-	-
Untreated check	-	-	-
Triclopyr	Triclon®	3841	0.8
Saflufenacil	Heat®	98	140
MCPA	Agritone®	6001	1.25
Quinclorac	Facet®	375	0.75
Dicamba	Dicamax®	7201	1.5
Pyroxsulam + Metribuzin	Tricea® + Sencor®480	18 + 144	0.4 + 0.3
Metribuzin + Metsulfuron	Sencor® 480 + Ally®	144 + 3.96	0.3 + 6.6
Pyroxsulam + Bentazon	Tricea® + Basagran®600	18 + 720	0.4 + 1.2
Bentazon + Metsulfuron	Basagran® 600+ Ally®	720 + 3.96	1.2 + 6.6

Table 3. Volunteer Enlist™ soybean control (%) in wheat at 7, 14, 21, and 28 days after treatments (DAT), in 2017.

Treatments	Days after treatments (DAT)			
	7	14	21	28
Weeded check	100 a[1]	100 a	100 a	100 a
Untreated check	0 e	0 d	0 c	0 d
Pyroxsulam	55 c	71 c	71 b	81 bc
Saflufenacil	86 a	83 b	81 ab	81 bc
Pyroxsulam + Saflufenacil	89 a	91 a	94 a	96 a
Pyroxsulam + Bentazon	65 b	73 c	70 b	74 c
Pyroxsulam + Metribuzin	47 d	79 b	86 a	86 b
Saflufenacil + Bentazon	88 a	85 b	81 ab	78 bc
Saflufenacil + Metribuzin	88 a	90 a	89 a	86 b
C.V. (%)	7.9	4.8	10.6	7.1

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test (p ≥ 0.05).

with saflufenacil was the most efficient in the control of volunteer Enlist™ soybean at 28 DAT, with a value higher than 95%, not differing from the weeded check. Herbicide mixtures aim to increase the weed control spectrum and the effectiveness of applications (Busi et al., 2019), thus evidencing its importance. The application of saflufenacil mixed with pyroxsulam resulted in a volunteer Enlist™ soybean control higher than the isolated application at 28 DAT.

The other treatments at 28 DAT did not differ statistically from each other, except for pyroxsulam + bentazon in relation to the mixtures saflufenacil + metribuzin and pyroxsulam + metribuzin: the control was approximately 12% higher in these cases (Table 3). This smaller control of volunteer Enlist™ soybean found for the mixture of pyroxsulam with bentazon is attributed to the selectivity of soybean to bentazon. This was also reported for the control of eudicotyledonous weeds during crop post-emergence.

The phytotoxicity to wheat crop promoted by the application of the isolated and mixed herbicides was low in all evaluations, except for the mixtures saflufenacil + bentazon and pyroxsulam + bentazon up to 14 and 21 DAT, respectively (Table 4). The expressive phytotoxicity to wheat found in the association of saflufenacil + bentazon can be attributed to the similar mode of action of these herbicides, which results in oxidative stress and lipid peroxidation of membranes (Hess, 2000), which in turn may cause an effect of joint phytotoxicity due to the plant's difficulty in metabolizing these molecules. In general, at 28 DAT, the crop showed recoverability in all herbicide treatments. The phytotoxicity was lower than 15% in all treatments but differed from the controls without herbicide application.

Table 4. Phytotoxicity (%) of herbicides to wheat at 7, 14, 21, and 28 days after treatments (DAT), in 2017.

Treatments	Days after treatment (DAT)			
	7	14	21	28
Weeded check	0.0 d[1]	0.0 d	0.0 c	0.0 d
Untreated check	0.0 d	0.0 d	0.0 c	0.0 d
Pyroxsulam	6.7 c	10.7 c	11.0 b	10.5 abc
Saflufenacil	8.2 c	10.0 c	10.0 b	6.7 c
Pyroxsulam + Saflufenacil	9.7 c	11.2 c	11.7 b	8.5 bc
Pyroxsulam + Bentazon	18.7 b	18.5 b	14.7 b	10.0 bc
Pyroxsulam + Metribuzin	6.2 c	10.7 c	12.5 b	8.3 bc
Saflufenacil + Bentazon	33.2 a	29.0 a	23.0 a	14.0 a
Saflufenacil + Metribuzin	9.0 c	11.7 c	14.7 b	11.2 ab
C.V. (%)	17.8	21.2	27.4	27.0

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test (p ≥ 0.05).

As for the yield components, the application of herbicides to the wheat crop promoted a reduction in NSE in relation to the weeded check in all treatments, except for isolated pyroxsulam, which did not differ from the weeded check (Table 5). However, although there was a difference in the phytotoxicity of herbicide treatments in relation to the weeded and untreated checks in all evaluations (Table 4), and also in NSE (Table 5), the final yield and the NE of wheat did not change. There was no difference between treatments and weed control for these variables. In addition to genetics and nutrition, the components of wheat yield are modified by environmental factors, including competition with weeds, with a direct influence on the management adopted (Vesohoski et al., 2011). The absence of differences in yield and wheat NE in relation to the weeded check can be justified by the reduced competition along the crop cycle with volunteer Enlist™ soybean plants after an efficient control. Otherwise, competition between weeds and wheat cultivation might cause reductions of up to 85% in wheat yield when growing together with ryegrass and wild radish (Lamego et al., 2013).

As for the control of volunteer Enlist™ soybean in the experiment conducted in the second growing season, there was an efficient control of the herbicide dicamba at 7 and 14 DAT, which was similar as the weeded check, remaining stable until the last evaluation (Table 6). A similar result, with a maximum control efficiency, occurred for soybeans after the application of 140 g a.i. ha^{-1} of dicamba (Johnson et al., 2012), showing the high sensitivity of soybean susceptible to this herbicide since this dose represents 20% of that used in the present work. The mixtures pyroxsulam + metribuzin and metribuzin + metsulfuron also did not differ from the weeded check and the treatment with dicamba at 21 and 28 DAT, with control higher than 95%.

Table 5. Yield components of wheat number of spikelets ear^{-1} (NSE), numbers of ear m^{-2} (NE), and grain yield (kg ha^{-1}), in 2017.

Treatments	NSE	NE	Grain yield
Weeded check	14.4 a[1]	335.7 a	3029 a
Untreated check	13.4 bc	220.0 b	1665 b
Pyroxsulam	13.6 ab	326.5 a	2877 a
Saflufenacil	13.3 bc	346.0 a	2900 a
Pyroxsulam + Saflufenacil	12.8 bc	341.5 a	2769 a
Pyroxsulam + Bentazon	12.6 c	329.3 a	2848 a
Pyroxsulam + Metribuzin	12.8 bc	330.2 a	2575 a
Saflufenacil + Bentazon	12.8 bc	367.3 a	2818 a
Saflufenacil + Metribuzin	13.2 bc	320.7 a	2775 a
C.V. (%)	4.0	13.5	9.8

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test (p ≥ 0.05).

Table 6. Volunteer Enlist™ soybean control (%) in wheat at 7, 14, 21, and 28 days after treatments (DAT), in 2018.

Treatments	Days after treatments (DAT)			
	7	14	21	28
Weeded check	100 a	100 a	100 a	100 a
Untreated check	0 h[1]	0 h	0 f	0 g
Triclopyr	19 gf	7 g	10 e	19 e
Saflufenacil	60 cd	69 d	77 b	87 cb
MCPA	16 g	13 f	17 d	16 f
Quinclorac	22 f	28 e	37 c	48 d
Dicamba	85 a	100 a	100 a	100 a
Pyroxsulam + Metribuzin	70 b	95 b	98 a	100 a
Metribuzin + Metsulfuron	64 bc	95 b	98 a	100 a
Pyroxsulam + Bentazon	54 e	70 dc	79 b	85 c
Bentazon + Metsulfuron	58 de	74 c	82 b	89 b
C.V. (%)	8.5	5.7	5.7	4.4

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test ($p \geq 0.05$).

The applications of triclopyr and MCPA resulted in the worst controls of volunteer Enlist™ soybean among treatments in all evaluations (Table 6). There were similar results for the control of volunteer soybean in sunflower by the application of triclopyr (120 g a.i. ha^{-1}), showing that it is not an alternative for the control of volunteer soybean (Brighenti, 2015). It is worth mentioning that the insertion of the sdpA gene, which confers resistance to 2,4-D in Enlist™ soybean, also provides resistance to the herbicides triclopyr and MCPA (Queiroz & Vidal, 2014), which may explain the low control level in these treatments. Quinclorac also showed unsatisfactory control for volunteer Enlist™ soybean, reaching a regular control at 28 DAT (Table 6).

For wild radish control, the mixtures pyroxsulam + metribuzin, metribuzin + metsulfuron, and pyroxsulam + bentazon did not differ from weed control after 14 DAT, achieving the maximum control efficiency at the end of the evaluation period (Table 7). In this evaluation, they did not differ from triclopyr and MCPA alone and from the mixture bentazon + metsulfuron, thus showing the high efficiency of these herbicides in the control of wild radish. The herbicide quinclorac, in addition to its inefficiency in controlling volunteer Enlist™ soybean, also obtained a low control for wild radish in all periods of evaluation.

Table 7. Wild radish control (%) in wheat at 7, 14, 21, and 28 days after treatments (DAT), in 2018.

Treatments	Days after treatment (DAT)			
	7	14	21	28
Weeded check	100 a	100 a	100 a	100 a
Untreated check	0 g[1]	0 g	0 e	0 d
Triclopyr	62 bc	87 de	94 bc	99 ab
Saflufenacil	83 a	93 bc	94 bc	97 b
MCPA	67 b	93 bcd	97 ab	100 a
Quinclorac	10 f	36 f	37 d	33 c
Dicamba	70 b	87 d	90 c	97 b
Pyroxsulam + Metribuzin	55 cde	99 a	99 a	100 a
Metribuzin + Metsulfuron	61 bcd	98 ab	100 a	100 a
Pyroxsulam + Bentazon	52 e	98 ab	99 a	100 a
Bentazon + Metsulfuron	54 de	87 cde	98 ab	100 a
C.V. (%)	10.9	4.7	4.1	2.1

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test ($p \geq 0.05$).

All herbicides used for the management of volunteer Enlist™ soybean and wild radish were highly selective for wheat, with a phytotoxicity below 15% in all periods of evaluation (Table 8). Corroborating these results, applications of auxin-mimicking herbicides at post-emergence of wheat, such as 2,4-D, dicamba + MCPA and fluroxypyr + MCPA, have shown to be selective to this crop with a low phytotoxicity (Robinson et al., 2015). Other studies have reported the selectivity of wheat with the associated use of clodinafop + metribuzin and pinoxaden + metribuzin (Abbas et al., 2016) or the use of the herbicides metribuzin, bentazon, and metsulfuron alone (Agostinetto et al., 2016).

The selectivity of auxin herbicides, in general, occurs through metabolization and conjugation, hydroxylation and cleavage, which results in non-phytotoxic metabolites in Poaceae (Peterson et al., 2016). Likewise, the metabolism by glutathione-S-transferase (GST) is the most important mechanism of selectivity for PROTOX-inhibiting herbicides (Matzenbacher et al., 2014). In particular for auxin herbicides, the application stage in wheat is important to ensure selectivity to the crop. The applications carried out before crop tillering result in grain sterility and yield losses, as well as applications after the terminal spikelet stage (Rodrigues et al., 2006).

Regarding hectoliter weight, there was no statistical difference in relation to the weeded check in all treatments, showing the maintenance of the quality and the health of wheat grains after applications (Table 9). For the weight of a thousand grains, the mixtures metribuzin + metsulfuron, pyroxsulam + bentazon, and bentazon + metsulfuron did not differ from the weeded check. There were no statistical differences for wheat yield for the treatments with MCPA, pyroxsulam + metribuzin, metribuzin + metsulfuron, and bentazon + metsulfuron in relation to the weeded check.

The increase in the frequency of resistance to herbicides in weed populations, as well as the presence of volunteer plants resulting from previously season that infest crops, demand efficient control practices. In this context, the association of

Table 8. Phytotoxicity (%) of herbicides to wheat at 10, 20, and 30 days after treatments (DAT), in 2018.

Treatments	Days after treatment (DAT)		
	10	20	30
Weeded check	0.0 d[1]	0.0 c	0.0 b
Untreated check	0.0 d	0.0 c	0.0 b
Triclopyr	12.0 a	4.0 a	1.5 a
Saflufenacil	10.0 ab	1.2 bc	0.5 b
MCPA	6.7 bc	0.5 bc	0.0 b
Quinclorac	8.0 bc	0.0 c	0.0 b
Dicamba	10.0 ab	2.0 b	0.7 b
Pyroxsulam + Metribuzin	6.0 c	0.5 bc	0.0 b
Metribuzin + Metsulfuron	7.5 bc	0.5 bc	0.0 b
Pyroxsulam + Bentazon	12.7 a	1.3 bc	0.5 b
Bentazon + Metsulfuron	4.7 c	0.5 bc	0.0 b
C.V. (%)	29.7	104.6	153.0

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test ($p \geq 0.05$).

Table 9. Yield components of wheat hectoliter weight (HW), weight of a thousand seeds (WTS) and grain yield (kg ha^{-1}), in 2018.

Treatments	HW	WTS	Grain yield
Weeded check	76.4 abc[1]	45.4 a	3615 ab
Triclopyr	75.3 c	42.9 d	3267 d
Saflufenacil	75.9 abc	43.1 cd	3322 d
MCPA	75.8 bc	43.9 bcd	3504 bc
Quinclorac	76.8 ab	43.5 bcd	3402 cd
Dicamba	76.1 abc	43.9 bcd	3314 d
Pyroxsulam + Metribuzin	76.2 abc	43.5 bcd	3690 a
Metribuzin + Metsulfuron	76.3 abc	44.7 ab	3579 abc
Pyroxsulam + Bentazon	77.1 a	44.9 ab	3430 cd
Bentazon + Metsulfuron	76.2 abc	44.5 abc	3526 abc
C.V. (%)	0.9	2.0	3.1

[1] Averages followed by the same lowercase letters in columns are not significantly different by Duncan test ($p \geq 0.05$).

herbicides with different mechanisms of action is essential, but always considering the physicochemical compatibility between herbicides, selectivity to the crop of interest, and the tolerance event in volunteer plants in order to obtain an effective control and ensure the sustainability of agricultural activity.

Conclusions

The association of the herbicides pyroxsulam and saflufenacil is efficient in the management of volunteer Enlist™ soybean, showing selectivity to wheat crop.

The isolated application of the herbicide dicamba and the associations of the herbicides pyroxsulam with metribuzin and of metribuzin with metsulfuron represent alternatives for selective management of volunteer Enlist™ soybean in wheat, in addition to efficiently controlling wild radish in post-emergence.

Compliance with Ethical Standards

Author contributions: Conceptualization: JG, DA; Data curation: Data curation: JG, CP, ASM, DA; Formal analysis: JG, GFB, CP, ASM; Funding acquisition: DA; Investigation: JG, GFB, CP, ASM, DA; Methodology: JG, DA; Project administration: JG, DA; Supervision: DA; Validation: JG, GFB, CP, ASM, DA; Visualization: JG, GFB, CP, ASM, DA; Writing – original draft: JG, GFB, CP, ASM, DA; Writing – review & editing: JG, GFB, DA.

Conflict of interest: The authors declare that there is no conflict of interest (professional or financial) that may influence the article.

Funding: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES (Finance Code 001) and Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Grants Number: 308363/2018-3).

Literature Cited

Abbas, T.; Nadeem, M.A.; Tanveer, A.; Ahmad, R. Identifying optimum herbicide mixtures to manage and avoid fenoxaprop-p-ethyl resistant *Phalaris minor* in wheat. Planta Daninha, v.34, n.4, p.787-794, 2016. https://doi.org/10.1590/s0100-83582016340400019.

Agostinetto, D.; Perboni, L.T.; Langaro, A.C.; Gomes, J.; Fraga, D.S.; Franco, J.J. Changes in photosynthesis and oxidative stress in wheat plants submmited to herbicides application. Planta Daninha, v.34, n.1, p.1-9, 2016. https://doi.org/10.1590/S0100-83582016340100001.

Alms, J.; Clay, S.A., Vos, D.; Moechnig, M. Corn yield loss due to volunteer soybean. Weed Science, v.64, n.3, p.495-500, 2016. https://doi.org/10.1614/WS-D-16-00004.1.

Bond, J.A.; Walker, T.W. Control of volunteer glyphosate-resistant soybean in rice. Weed Technology, v.23, n.2, p.225-230, 2009. https://doi.org/10.1614/WT-08-156.1.

Brazil. Ministry of Agriculture, Livestock and Supply. Analysis seeds rules. 1.ed. Brasília: Mapa; ACS, 2009. 399 p.

Brazil´s Ministry of Agriculture. Agrofit 2021. http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. 24 Jan. 2021.

Brighenti, A.M. Control of volunteer soybean plants in sunflower crop. Pesquisa Agropecuária Tropical, v.45, n.3, p.274-281, 2015. https://doi.org/10.1590/1983-40632015v4533999.

Busi, R.; Powles, S.B.; Beckie, H.J.; Renton, M. Rotations and mixtures of soil-applied herbicides delay resistance. Pest Management Science, v.76, n.2, p.487-496, 2019. https://doi.org/10.1002/ps.5534.

Goggin, D.E.; Cawthray, G.R.; Powles, S.B. 2,4-D resistance in wild radish: reduced herbicide translocation via inhibition of cellular transport. Journal of Experimental Botany, v.67, n.11, p.3223–3235, 2016. https://doi.org/10.1093/jxb/erw120.

Heap, I. International survey of herbicide resistant weeds. http://weedscience.org. 24 Jan. 2021.

Hess, F.D. Light-dependent herbicides: an overview. Weed Science, v.48, n.2, p.160-170, 2000. https://doi.org/10.1614/0043-1745(2000)048[0160:LDHAO]2.0.CO;2.

Johnson, V.A.; Fisher, L.R.; Jordan, D.L.; Edmisten, K.E.; Stewart, A.M.; York, A.C. Cotton, peanut, and soybean response to sublethal rates of dicamba, glufosinate, and 2,4-D. Weed Technology, v.26, n.2, p.195–206, 2012. https://doi.org/10.1614/WT-D-11-00054.1.

Knezevic, S.Z.; Weise, S.F; Swanton, C.J. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). Weed Science, v.42, n.4, p.568-573, 1994. https://doi.org/10.1017/S0043174500076967.

Lamego, F.P.; Kaspary, T.E.; Ruchel, Q.; Gallon, M.; Basso, C.J.; Santi, A.L. Management of glyphosate resistant *Conyza bonariensis*: winter cover crops and herbicides in soybean pre-seeding. Planta Daninha, v.31, n.2, p.433-442, 2013. https://doi.org/10.1590/S0100-83582013000200022.

Matzenbacher, F.D.O.; Vidal, R.A.; Merotto Jr, A.; Trezzi, M.M. Environmental and physiological factors that affect the efficacy of herbicides that inhibit the enzyme protoporphyrinogen oxidase: a literature review. Planta Daninha, v.32, n.2, p.457-463, 2014. https://doi.org/10.1590/S0100-83582014000200024.

Moechnig, M.J.; Stoltenberg, D.E; Boerboom, C.M.; Binning, L.K. Empirical corn yield loss estimation from common lambsquarters (*Chenopodium album*) and giant foxtail (*Setaria faberi*) in mixed communities. Weed Science, v.51, n.3, p.386-393, 2003.https://doi.org/10.1614/0043-1745(2003)051[0386:ECYLEF]2.0.CO;2.

National Supply Company – Conab. Safra brasileira de grãos. https://www.conab.gov.br/info-agro/safras/graos. 24 Jan. 2021.

Peterson, M.A.; Mcmaster, S.A.; Riechers, D.E.; Skelton, J.; Stahlman, P.W. 2, 4-D past, present, and future: a review. Weed Technology, v.30, n.2, p.303-345, 2016. https://doi.org/10.1614/WT-D-15-00131.1.

Queiroz, A.R.S.D.; Vidal, R.A. O desenvolvimento de culturas tolerantes ao herbicida diclorofenoxiacetato: Revisão de literatura. Planta Daninha, v.32, n.3, p.649-654, 2014. https://doi.org/10.1590/S0100-83582014000300021.

Robinson, A.P.; Simpson, D.M.; Johnson, W.G. Response of aryloxyalkanoate dioxygenase-12 transformed soybean yield components to postemergence 2, 4-D. Weed Science, v.63, n.1, p.242-247, 2015. https://doi.org/10.1614/WS-D-14-00036.1.

Rodrigues, O.; Marchese, J.A.; Vargas, L.; Velloso, J.A.; Rodrigues, R.C. Efeito da aplicação de herbicida hormonal em diferentes estádios de desenvolvimento de trigo (*Triticum aestivum* L. Cvs. Embrapa 16 e BR 23). Revista Brasileira de Herbicidas, v.5, n.1, p.19-29, 2006. https://doi.org/10.7824/rbh.v5i1.41.

Skelton, J.J.; Simpson, D.M.; Peterson, M.A.; Riechers, D.E. Biokinetic Analysis and Metabolic Fate of 2,4-D in 2,4-D-Resistant Soybean (*Glycine max*). Journal of Agricultural and Food Chemistry, v.65, n.29, p.5847-5859, 2017. https://doi.org/10.1021/acs.jafc.7b00796.

Terasawa, J.; Panobianco, M.; Possamai, E.; Soares, K.H. Antecipação da colheita na qualidade fisiológica de sementes de soja. Bragantia, v.68, n.3, p.765-773, 2009. https://doi.org/10.1590/S0006-87052009000300025.

Vesohoski, F.; Marchioro, V.S.; De Assis Franco, F.; Cantelle, A. Componentes da produtividade de grãos em trigo e seus efeitos diretos e indiretos na produtividade. Ceres, v.58, n.3, p.337-341, 2011. https://doi.org/10.1590/S0034-737X2011000300014.

Zobiole, L.H.S.; Kalsing, A. Eficácia de misturas formuladas contendo halauxifen-methyl no controle de soja voluntária DAS-444Ø6-6 (Enlist E3™). Revista Brasileira de Herbicidas, v.16, n.3, p.192-197, 2017. https://doi.org/10.7824/rbh.v16i3.548.