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# Selectivity and efficacy of herbicides applied to the wheat crop

*Seletividade e eficácia de herbicidas aplicados à cultura do trigo*

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**ABSTRACT**

When not controlled efficiently, weeds in wheat crop stands may affect both the grain quality and yield production. This work aimed to assess the selectivity and efficacy of herbicides applied to control weeds in the wheat cultivar TBIO Sinuelo. Two experiments were set up to assess the selectivity and the efficacy of herbicides applied to wheat in randomized blocks design with four replications. Treatments tested were: iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, clodinafop-propargyl, [bentazon + imazamox], saflufenacil, bentazon, carfentrazone-ethyl, imazamox, pendimethalin, [sulfentrazone + diuron], plus two control treatments, one weeded and the other infested. The greatest damages to wheat were caused by imazamox and the commercial mixture [bentazon + imazamox] with phytotoxicity of approximately 50%. On the other hand, applying the commercial mixture [sulfentrazone + diuron] allowed the highest wheat grain yield. The use of clodinafop-propargyl and pyroxsulam promoted the best control of *Lolium multiflorum*, with 100 and 98.25% at 21 days after treatment application, respectively. The control above 90% of *Raphanus raphanistrum* was reported with iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, [bentazon + imazamox], saflufenacil, bentazon, and carfentrazone. Clodinafop-propargyl was the most efficient on ryegrass, and iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, saflufenacil, and carfentrazone performed best on the turnip. Pyroxsulam was the treatment that showed, in both experiments, the best results for all-grain yield components, especially for grain yield.

**KEYWORDS:** *Triticum aestivum*, *Lolium multiflorum*, *Raphanus raphanistrum*.

**RESUMO**

As plantas daninhas ocasionam efeitos negativos na produtividade e na qualidade dos grãos da cultura do trigo quando não controladas de modo eficiente. Assim sendo, objetivou-se com os trabalhos avaliar a seletividade e a eficácia de herbicidas aplicados para o manejo de plantas daninhas infestante da cultivar de trigo TBIO Sinuelo. Foram instalados dois experimentos, um para avaliar a seletividade e outro a eficácia de herbicidas aplicados em trigo, em blocos casualizados, com quatro repetições. Os tratamentos testados foram: iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, clodinafope-propargil, [bentazon + imazamox], saflufenacil, bentazon, carfentrazone-ethyl, imazamox, pendimethalin, [sulfentrazone + diuron], mais duas testemunhas uma capinada e outra infestada. Os herbicidas que ocasionaram as maiores injúrias ao trigo foram o imazamox e a mistura comercial de [bentazon + imazamox] com fitotoxicidade próxima a 50%. A aplicação da mistura comercial de [sulfentrazone + diuron] demonstrou a maior produtividade de grãos do trigo. O uso de clodinafope-propargil e pyroxsulam apresentaram os melhores controles de *Lolium multiflorum*, com 100 e 98,25%, aos 21 dias após a aplicação dos tratamentos, respectivamente. Ocorreu controle acima de 90% de *Raphanus raphanistrum* com uso de iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, [bentazon + imazamox], saflufenacil, bentazon e carfentrazone. O clodinafope-propargil demonstra o maior controle para o azevém e o iodosulfuron-ethyl, pyroxsulam, metsulfurom-metílico, 2,4-D, saflufenacil e carfentrazone para o nabo. O pyroxsulam foi o tratamento que demonstrou, nos dois experimentos, os melhores resultados para os componentes da produção, especialmente para a produtividade da cultura.

**PALAVRAS-CHAVE:** *Triticum aestivum*, *Lolium multiflorum*, *Raphanus raphanistrum*.

## INTRODUCTION

Wheat (*Triticum aestivum*) is the second most widely grown cereal in the world, with estimated production for the 2021 crop of 780 million tons of grain (FAO 2021). Brazil ranks 17th among the world's largest producers of wheat, with production estimates of more than 6.3 million tons (CONAB 2021). The southern region of Brazil, mainly the states of Paraná and the Rio Grande do Sul are the largest producers with 2.9 and 2.5 million tons produced annually, respectively (CONAB 2021).

Wheat grains are used both for human and animal food, being of high importance for feeding a large part of the world's population (FAO 2021). The potential productivity and quality of wheat are related to the effect of several factors such as climate, soil, and the management adopted with the crop (GALON et al. 2019, TAVARES et al. 2019). In addition, the interference caused by weeds affects the increase in productivity and quality of wheat grains (GALON et al. 2019, TAVARES et al. 2019).

Weeds compete with wheat for the resources available in the environment such as water, light, nutrients, release allelopathic substances, besides being hosts of pests and diseases that affect the crop leading to losses in productivity that can range from 18 to 82%, in addition to the effect on the quality of harvested grains, increased production costs and reduced profit margin for the producer (AGOSTINETTO et al. 2008, GALON et al. 2019, TAVARES et al. 2019).

Among the weed species that cause interference and damage to the wheat crop are ryegrass *(Lolium multiflorum*) and turnip rape (*Raphanus raphanistrum* and *R. sativus*) (AGOSTINETTO et al. 2008). Ryegrass reduces the productivity and quality of wheat grains and has similar morphological characteristics with the crop - belongs to the same botanical family (Poaceae) - causing similar needs for resources and difficulties in using chemical control methods with herbicides (AGOSTINETTO et al. 2008). Ryegrass also presents several cases of resistance to herbicides inhibitors of acetolactate synthetase - ALS, acetyl-coenzyme A carboxylase -ACCase, and enol pyruvyl shikimate phosphate synthetase - EPSPs (HEAP 2021).

Similarly, turnip is one of the leading causes of yield losses in winter crops. Moreover, it already presents several cases of resistance to herbicides used for its control in Brazil and other countries, including ALS inhibitors (COSTA & RIZZARDI 2014, HEAP 2021).

The chemical control method is the most used by farmers to manage weeds due to its efficiency, practicality, speed, and lower cost when compared to other methods (SCHMITZ et al. 2018, MICHELON et al. 2021). However, in the South of Brazil, the herbicides used in the post-emergence of wheat predominantly belong to ACCase and ALS inhibitors (MICHELON et al. 2021). Therefore, the most recommended for weed control in wheat and available in larger quantities are the ALS inhibitors (PIASECKI et al. 2017). However, these herbicides are the ones that have shown many cases of resistant weeds in recent years (HEAP 2021), and in some countries, the concern lies in the time required for chemical control to show an effect on infective species in wheat crops (WALSH 2019).

It is important to note that the increasing cases of weed resistance are linked to high selection pressure due to the disordered application of herbicides of the same mechanism of action, to the scarce alternatives of products registered for use in the wheat crop, and also to the lack of crop rotation and active ingredients (COSTA & RIZZARDI 2014, WALSH 2019).

Herbicides, when applied to crops, can exert direct or indirect effects on the growth and development of plants, causing changes in physiological and metabolic processes, intoxication, deregulation of defense mechanisms, cellular oxidation, changes in nutrient uptake, among others (RIZZARDI et al. 2003, GALON et al. 2015, BARI et al. 2020). The incorrect use of herbicides can cause negative interference on the components of grain yield of crops, inefficiency in weed control, and negative impacts on agroecosystems (ZAKARIYYA et al. 2013, GALON et al. 2015, BARI et al. 2020).

New studies evaluating the selectivity and efficacy of herbicides are important to seek other chemical control alternatives with different mechanisms of action for the management of weeds infesting wheat - even if these products are not yet registered for the crop - as some of the molecules tested in this research. Thus, the objective was to evaluate the selectivity and efficacy of herbicides for the management of ryegrass and turnip rape weeds of the wheat cultivar TBIO Sinuelo.

## MATERIAL AND METHODS

Two field experiments were installed in the experimental area of the Federal University of the Southern Frontier (UFFS), Erechim/RS, in the 2018 agricultural year, according to Figure 1. In the first experiment, the selectivity of the herbicides to wheat was evaluated, and in the second, the control effectiveness on ryegrass (*Lolium multiflorum*) and turnip (*Raphanus sativus*) weeds were studied. The soil of the experimental area is classified as Red Latosol Alumino ferric humic (SANTOS et al. 2018). Its pH correction and fertilization were performed according to the physicochemical analysis following the technical recommendations for wheat culture (CQFS-RS/SC 2016).

Figure 1. View of Experiment I (A) and Experiment II (B) at the beginning of wheat crop development. UFFS, Erechim/RS, 2018.

The chemical and physical characteristics of the soil were: pH in water of 5.1; MO = 3.0%; P= 5.2 mg dm$^{-3}$; K= 118.0 mg dm$^{-3}$; $Al^{3+}$=0.3 cmol$_c$ dm$^{-3}$; $Ca^{2+}$= 5.5 cmol$_c$ dm$^{-3}$; $Mg^{2+}$= 3.0 cmol$_c$ dm$^{-3}$; CTC(t)= 7.4 cmol$_c$ dm$^{-3}$; CTC (pH=7,0)= 16.6 cmol$_c$ dm$^{-3}$; H+Al= 7,7 cmol$_c$ dm$^{-3}$; SB= 53% and Clay= 60%. Wheat was sown in a no-till system, and the vegetation was previously desiccated with glyphosate (1,440 g ha$^{-1}$) + saflufenacil (70 g ha$^{-1}$) + Dash (0.5% v/v). The rainfall and average temperature (ºC) during the period of the experiments can be seen in Figure 2.

The experiments were set up in randomized blocks, with four repetitions and 14 treatments. Each experimental unit had dimensions of 5 x 2.72 m, totaling an area of 13.6 m$^2$, containing 16 sowing lines spaced at 0.17 m. The useful area of the plots corresponded to 6.8 m$^2$ (4 x 1.7 m), and the ten central rows of wheat were harvested, discarding the lateral borders for the analyses.

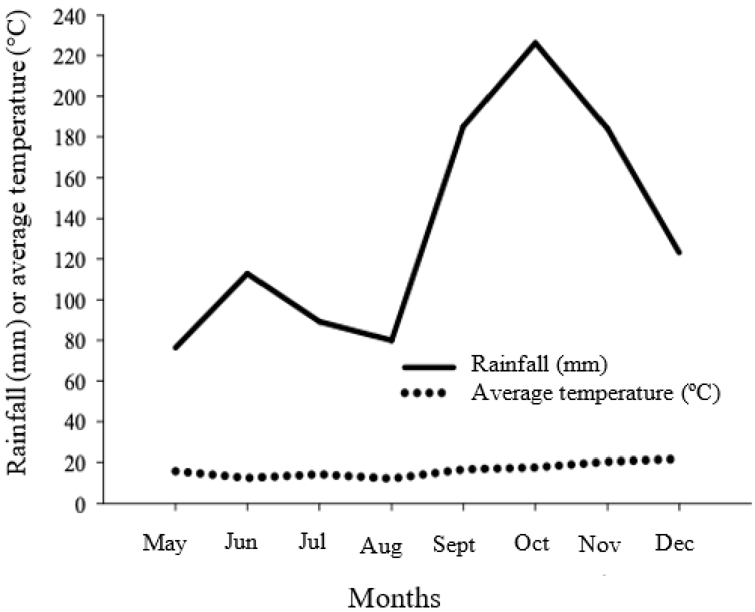


Figure 2. Average temperature (ºC) and rainfall (mm) during the period of conducting the experiments from June to November 2018. Source: (INMET 2021).

Sowing of the experiments occurred on 06/15/2018, both for the selectivity and efficacy trials, using the medium-late cycle wheat cultivar, TBIO Sinuelo, through a seeder/adulator. The average seed density was 50 plants per linear meter, or 300 plants m$^{-2}$. For base fertilization, 200 kg ha$^{-1}$ of formula 05-30-15 (N-$P_2O_5$-$K_2O$) was used, and in top dressing, 140 kg ha$^{-1}$ of nitrogen in the form of urea (45% N) was applied, divided into two periods, the first during tillering and the second during the elongation phase.

The herbicides were applied using a CO2 pressurized precision knapsack sprayer equipped with four DG 110.02 fan spray tips, maintaining a constant pressure of 210 kPa and a travel speed of 3.6 km h-1, which provided a flow rate of 150 L $ha^{-1}$ of herbicide solution. The treatments used in both experiments and the doses of herbicides are shown in Table 1.

Table 1. Treatments used in the experiments, respective doses, adjuvant, and application modality. UFFS/Erechim/RS, 2018.

| Treatments | Dose (g $ha^{-1}$) i.a | Doses (g/L $ha^{-1}$) P.C | Adjuvant (% v/v ou L) | | Application modality |
|---|---|---|---|---|---|
| Control weeded | --- | --- | --- | --- | --- |
| Control infested* | --- | --- | --- | --- | --- |
| Iodosulfuron | 3.5 | 70 | Hoefix | 0.5 L | Post-emergence |
| Pyroxsulam | 18 | 0.4 | Vejet Oil | 0.5 L | Post-emergence |
| Metsulfuron-methyl | 3.96 | 6.6 | Dash | 0.15 L | Post-emergence |
| 2,4-D | 806 | 1.0 | --- | --- | Post-emergence |
| Clodinafope-propargil | 48 | 0.2 | Assist | 0.5 % v/v | Post-emergence |
| [Bentazon+imazamox] | 600 +28 | 1.0 | Assist | 0.5 % v/v | Post-emergence |
| Saflufenacil | 49 | 70 | Assist | 0.5 % v/v | Post-emergence |
| Bentazon | 720 | 1.2 | Assist | 0.5 % v/v | Post-emergence |
| Carfentrazone-ethyl | 120 | 0.3 | Assist | 0.5 % v/v | Post-emergence |
| Imazamox | 42 | 60 | Dash | 0.5% v/v | Post-emergence |
| Pendimethalin | 1500 | 2.0 | --- | --- | Pre-emergence |
| [Sulfentrazone+diuron] | 175+350 | 1.0 | --- | --- | Pre-emergence |

* In the selectivity test there was no infested control treatment.

The herbicides [bentazon+imazamox] and [sulfentrazone+diuron] are commercial mixtures formulated by the company that owns the molecules. Each herbicide received the adjuvant recommended by the respective manufacturer. The herbicides pendimethalin and [sulfentrazone+diuron] were applied in pre-emergence and all others in post-emergence of the crop. Some of the products tested are not registered to be applied in wheat. However, they were used to evaluate the possibility of application in the future as a new alternative for the chemical control of weeds.

The species' environmental conditions at the time of application of the treatments in pre- (06/16/2018) and post-emergence (07/13/2018) were, respectively, relative humidity of 80 and 70%, winds of 4.5 and 5.0 km $h^{-1}$. For both application modes, the sky was open, and the temperature was 10°C. The average density of wheat plants was 47 plants per linear meter determined at the beginning of tillering. When the post-emergence herbicides were applied, the wheat was in the initial tillering phase, the turnip and ryegrass with four to six leaves and four leaves to one tiller, at densities of 30 and 40 plants $m^{-2}$, respectively. The weed population in the experimental area was counted in the center of the infested controls using a wooden square measuring 0.5 x 0.5 m (0.25 $m^2$).

The variables evaluated in the experiments were phytotoxicity of the wheat cultivar TBIO Sinuelo, control of turnip and ryegrass weeds, number of ears per area, length of ears, number of full and sterile (shriveled) grains, thousand-grain weight, hectolitre weight (HW), and grain yield.

The phytotoxicity evaluations were performed visually at 7, 14, 21, 28, and 35 days after applying treatments (DAT). The control of turnip and ryegrass was carried out following the same phytotoxicity methodology, at 7, 14, 21, and 28 DAT. After, percentage scores were assigned, being zero (0%) for treatments with no damage to wheat or efficiency in turnip and ryegrass and one hundred (100%) for plant death (SBCPD 1995).

The variables evaluated in the pre-harvest of the wheat crop were the number of ears per area (0.25 $m^2$), the number of full and sterile grains per ear, and the length of the ears. The number of ears was measured in the center of each experimental unit using a wooden square with dimensions of 0.5 x 0.5 m, and this variable was only evaluated in the selectivity test. Ten ears were randomly collected from each experimental unit to determine by counting the number of full and sterile grains and using a graduated ruler the length of ears.

After manual harvest and screening of the wheat in a 6.8 m² area, the hectoliter weight - PH (kg $hl^{-1}$), the thousand-grain mass (g), and grain yield (kg $ha^{-1}$) were determined. First, the PH was determined using a Dalle Molle scale, model 40. Next, the mass of one thousand grains was measured by counting eight samples of 100 grains each and then weighed on an analytical balance. Grain yield was then estimated and extrapolated to kg $ha^{-1}$. For the analyses, the humidity of the grains was adjusted to a content of 13%.

The data were submitted to variance analysis using the F test, and when significant effects were observed, the treatment means were compared using the Scott-Knott test at 5% probability.

## RESULTS AND DISCUSSION

### EXPERIMENT I - Evaluation of selectivity of herbicides applied to the wheat cultivar TBIO Sinuelo.

Significant effects were observed in the treatments tested for the variables phytotoxicity, number of ears, number of full and sterile grains, hectolitre weight, and grain yield for the selectivity experiment (Tables 2 and 3).

The phytotoxicity of herbicides on the wheat cultivar TBIO Sinuelo showed significant results at 7 and 14 DAT. Only the pre-emergent herbicides, [sulfentrazone + diuron] and pendimethalin caused the greatest damage to the crop (Table 2). At 21 DAT the treatments that caused the highest percentage of phytotoxicity were imazamox followed by [bentazon + imazamox], saflufenacil, carfentrazone-ethyl, and [sulfentrazone + diuron]. At 28 and 35 DAT, imazamox followed by [bentazon + imazamox] caused the most significant phytotoxicity to the wheat crop. The other herbicide treatments showed low phytotoxicity to wheat, equaling the control with weeding or with lower rates than imazamox and [bentazon + imazamox], in all evaluations from 7 to 35 DAT.

Table 2. Phytotoxicity (%) to the wheat cultivar TBIO Sinuelo as a function of herbicide application. UFFS, Erechim/RS, 2018.

| Treatments | Phytotoxicity (%) | | | | |
|---|---|---|---|---|---|
| | 07 DAT[1] | 14 DAT | 21 DAT | 28 DAT | 35 DAT |
| Control weeded | 0.00 c[2] | 0.00 c | 0.00 d | 0.00 c | 0.00 d |
| Iodosulfuron | 0.00 c | 0.00 c | 6.75 c | 0.00 c | 0.00 d |
| Pyroxsulam | 0.00 c | 0.00 c | 7.25 c | 0.00 c | 0.00 d |
| Metsulfuron-methyl | 0.00 c | 0.00 c | 1.00 d | 0.00 c | 0.00 d |
| 2,4-D | 0.00 c | 0.00 c | 6.00 c | 0.00 c | 0.00 d |
| Clodinafope-propargil | 0.00 c | 0.00 c | 6.50 c | 2.50 c | 3.50 c |
| [Bentazon+imazamox] | 0.00 c | 0.00 c | 15.00 b | 50.00 a | 47.50 b |
| Saflufenacil | 0.00 c | 0.00 c | 11.50 b | 3.25 c | 5.00 c |
| Bentazon | 0.00 c | 0.00 c | 6.00 c | 0.00 c | 0.00 d |
| Carfentrazone-ethyl | 0.00 c | 0.00 c | 10.25 b | 3.50 c | 4.50 c |
| Imazamox | 0.00 c | 0.00 c | 19.25 a | 40.00 b | 55.00 a |
| Pendimethalin | 6.25 b | 5.00 b | 4,50 c | 0.00 d | 0.00 d |
| [Sulfentrazone+diuron] | 25.00 a | 46.25 a | 13.75 b | 5.25 c | 6.25 c |
| C.V. (%) | 84.87 | 37.50 | 40.92 | 39.36 | 28.96 |

[1] Days after treatment application. [2] Means followed by the same lower case letters in the column do not differ by the Scott-Knott test at 5% probability.

In the study conducted by PIASECKI et al. (2017), metsulfuron-methyl, saflufenacil, and the mixture of both used in the wheat cultivar TBIO Iguaçu showed the highest phytotoxicity when compared to other treatments applied to the crop. GALON et al. (2015), when evaluating the phytotoxicity of herbicides applied to control weeds of wheat, observed that iodosulfuron, metsulfuron-methyl, 2,4-D, cyhalofop-p-buthyl, penoxsulam, and pyroxsulam showed symptoms below 10%, considered low to the wheat cultivars TBIO Quartzo and TBIO Pioneiro in all evaluations performed. The facts reported above were also observed in this present research.

Table 3. Effect of herbicides on the number of ears m$^{-2}$ (N. ears. - m$^{-2}$) ears length (length. ears - cm), number of full grains, number of sterile grains, thousand-grain weight (PMG - g), hectoliter weight (PH - kg hl$^{-1}$), and grain yield (Prod. - kg ha$^{-1}$) of wheat cultivar TBIO Sinuelo crop. UFFS, Erechim/RS, 2018.

| Treatments | Wheat Grain Yield Components | | | | | | |
|---|---|---|---|---|---|---|---|
| | Number of ears m$^{-2}$ | Ears length | Full grains | Sterile grains | PMG (g) | PH (kg hl$^{-1}$) | Prod. (kg ha$^{-1}$) |
| Control weeded | 525.00 a[1] | 7.63$^{ns}$ | 27.50 b | 7.25 a | 31.31 $^{ns}$ | 75.75 a | 3127.97 b |
| Iodosulfuron | 404.00 b | 7.58 | 31.50 a | 10.25 a | 32.45 | 77.00 a | 3317.32 b |
| Pyroxsulam | 540.00 a | 7.23 | 31.25 a | 4.50 b | 30.59 | 76.50 a | 3703.86 a |
| Metsulfuron-methyl | 476.00 a | 7.73 | 27.50 b | 5.00 b | 29.55 | 75.75 a | 3907.11 a |
| 2,4-D | 488.00 a | 7.90 | 30.75 a | 4.75 b | 32.44 | 78.75 a | 3872.54 a |
| Clodinafope-propargil | 512.00 a | 7.11 | 32.00 a | 3.00 b | 30.60 | 76.50 a | 3292.78 b |
| [Bentazon+imazamox] | 412.00 b | 7.35 | 28.00 b | 3.00 b | 31.24 | 75.25 a | 2951.08 b |
| Saflufenacil | 410.00 b | 7.50 | 27.50 b | 5.75 b | 31.29 | 77.75 a | 3530.41 a |
| Bentazon | 440.00 b | 7.53 | 28.25 b | 2.75 b | 32.75 | 77.00 a | 3997.86 a |
| Carfentrazone-ethyl | 453.00 b | 7.45 | 29.50 b | 2.00 b | 31.89 | 77.25 a | 3802.54 a |
| Imazamox | 423.00 b | 7.35 | 25.25 b | 9.25 a | 30.64 | 70.25 b | 2536.64 c |
| Pendimethalin | 457.00 b | 7.55 | 28.25 b | 2.50 b | 31.60 | 76.75 a | 3215.84 b |
| [Sulfentrazone+diuron] | 542.00 a | 7.50 | 34.25 a | 2.75 b | 30.94 | 76.25 a | 4258.93 a |
| C.V. (%) | 8.26 | 3.46 | 7.92 | 44.32 | 3.96 | 2.27 | 9.59 |

[1] Means followed by the same lower case letters in the column do not differ by the Scott-Knott test at 5% probability. $^{ns}$ not significant at 5% error probability.

The commercial mixture of herbicides [bentazon+imazamox] is not registered for application in wheat only the use of bentazon alone for the control of weeds in cereal is recommended (AGROFIT 2021). Imazamox causes negative effects on wheat because it binds to the enzyme acetolactate synthetase (ALS) and prevents the production of branched-chain amino acids in the plant, causing yellowing and purpling of young leaves in susceptible plants (RODRIGUES & ALMEIDA 2018). In addition, the mixture [bentazon+imazamox] caused the death of plants of the wheat cultivars BRS 264 and BRS 404 sown in the Brazilian Cerrado (OLIVEIRA 2019).

The results reported in this study agree with the studies performed by VARGAS & ROMAN (2005). In addition, these authors evaluated the effect of herbicides verified selectivity of both metsulfuron-methyl, 2,4-D, and iodosulfuron for wheat, triticale and rye. Similarly, GALON et al. (2014) used these products on the cultivars Barley MN610 and Crioula.

Regarding the variables related to the components of wheat production, it was observed that none of the evaluated treatments caused a significant effect on the length of ears and weight of a thousand grains (Table 3). In the study conducted by GALON et al. (2014), the length of ears varies depending on the cultivar or genotype. However, the application of 2,4-D in barley did not cause an adverse effect compared to the control without herbicides. Similarly, RAJ et al. (2020), when evaluating the efficacy of different herbicides in wheat, found that among the treatments tested, none was significant for the variables plant height and weight of one thousand grains, which is similar in parts to what was observed in this study.

The treatments with pyroxsulam, metsulfuron-methyl, 2,4-D, clodinafop-propargyl, and the commercial mixture of [sulfentrazone + diuron] showed similar results with the weeded control in the number of ears per $m^{-2}$ (Table 3). The other treatments showed a lower number of wheat ears than the weeded witness, being associated with phytotoxicity caused by the treatments that directly affected this component. In the study by GALON et al. (2015), when testing several herbicides, inhibitors of ALS, photosystem II, and ACCase also observed similarity in the number of ears of wheat cultivars TBIO Quartzo and TBIO Pioneiro. The study conducted by RODRIGUES et al. (2006) shows that the behavior of the herbicide dicamba did not affect the number of ears, which is similar to the result of the present study regarding the use of 2,4-D, since both belong to the synthetic auxin inhibitors.

The treatments with pyroxsulam, the 2,4-D, clodinafop-propargyl, and [sulfentrazone+diuron] showed the highest number of full grains and the lowest number of sterile grains per ear of wheat. The other treatments were significantly lower, equaling the weeded control with fewer full grains and more sterile grains per ear (Table 3). This is associated with the direct and/or indirect interference of herbicides in the growth and development of plants, and that sometimes the damage caused by the products are not perceptible in visual evaluations of phytotoxicity carried out in the field, as also reported in their studies Das et al. (2003) and RIZZARDI et al. 2003. The higher number of sterile grains observed in the weeded witness may be due to the negative effects of weeding, affecting the root system, weed regrowth and ineffective in the crop seeding line, as found by BASSO et al. (2018). The results of GALON et al. (2015) corroborate the results of the present study when testing several herbicides belonging to various mechanisms of action and found a higher number of full grains and fewer sterile grains in the wheat cultivar TBIO Quartzo when applying herbicides that inhibit ALS, a synthetic auxin, photosystem II and ACCase.

The treatments with iodosulfuron and imazamox herbicides were statistically equal to the weeded control, presenting the highest number of sterile (shriveled) grains (Table 3). The treatment with iodosulfuron showed the highest number of filled grains and the highest number of sterile grains. This may have occurred because this treatment presented the lowest number of ears $m^{-2}$ and those with the highest total number of grains. RODRIGUES et al. (2006) verified that the use of pyroxsulam caused, in general, the lowest number of sterile grains for barley, which is similar in parts to the data obtained in this study. Results found by BERNAT et al. (2018), when using 2,4-D, verified that herbicides can cause stress in plants causing them to increase the growth of certain organs or effect greater expression, such as the greater number of full grains.

For the hectolitre weight (HP), it was observed that only imazamox differed from the other herbicides, including the weeded control, presenting the lowest results (Table 3). This variable is of great importance in the classification and commercialization of wheat, since the higher the PH, the higher the flour yield and better quality (ORMOND et al. 2013). According to the Normative Instruction number 7 of August 15, 2001, of the Ministry of Agriculture, Livestock and Supply (BRASIL 2001), wheat grains are classified into three types: 1, 2, and 3 with a minimum of 78, 75, and 70 kg $hl^{-1}$, respectively, and these parameters are intrinsically linked by the uniformity, shape, density, and size of the grain, in addition to the content of foreign matter and broken of the sample (NUNES et al. 2011). Based on this, in the present study, only the treatment involving the herbicide 2,4-D demonstrated the best PH to produce a type 1 flour, of the best quality for the industry.

The results show that imazamox presented the lowest grain yield of wheat, corroborating the high rates of phytotoxicity to the crop, especially after 21 DAT (Table 2 and 3). It is noteworthy that ALS inhibitor herbicides show symptoms of injury caused in plants late compared to other herbicides (RODRIGUES & ALMEIDA 2018), as in this case after 21 DAT. The application of herbicides for the management of weeds infesting crops, besides the environmental impact they can cause in agroecosystems, can interfere directly and/or indirectly in the growth and development of plants (RIZZARDI et al. 2003, BERNAT et al. 2018), which consequently reflects in the productivity or quality of harvested grains, as seen in the present work.

The highest grain yields were observed in the treatments with pyroxsulam, metsulfuron-methyl, 2,4-D, saflufenacil, bentazon, carfentrazone-ethyl, and [sulfentrazone+diuron], even higher than the control with weeding (Table 3). The other treatments presented yield an intermediate between the lowest and the highest observed in the experiment. Similarly, in the study by CHHOKAR et al. (2007), the authors found that the application of herbicides such as metsulfuron-methyl associated with sulfosulfuron showed the highest levels of productivity.

The weeded control showed an average reduction of 18.20% in wheat grain yield when compared to the average of all herbicide treatments used in the study (Table 3). This fact occurs because weeding can damage plants, including their roots, in addition to the lack of control in the wheat sowing line. Furthermore, after the cleaning or weeding operations, the rains favor the regrowth/weeding of the weeds, causing competition with the crop again. In addition, the use of the mechanical control method (weeding) in wheat crops is expensive, not very efficient, and requires excessive labor, which generates high costs when compared to the chemical control method. This fact was also reported by BASSO et al. (2018) when working with the management of weeds infesting the corn crop with treatments involving herbicides and weeding.

Imazamox reduced the grain yield of the wheat cultivar TBIO Sinuelo by 40.44% when compared to the highest yield obtained with the commercial mixture of [sulfentrazone+diuron] (Table 3), caused by the high phytotoxicity (Table 2) that imazamox provided to the crop, as explained previously. However, even though [sulfentrazone + diuron] caused high injury to wheat, until 21 DAT, the wheat managed to recover in time to express high grain yields.

The herbicides pyroxsulam, metsulfuron-methyl, 2,4-D, and [sulfentrazone+diuron] showed a higher number of ears, ear length, number of full grains, thousand-grain weight, hectolitre weight, grain yield, and lower number of sterile grains for the wheat cultivar TBIO Sinuelo (Table 3). In addition, the herbicides showed low phytotoxicity, and the crop was able to reverse the damage caused by them and maintain high productivity. Studies by OLIVEIRA (2019) and RAJ et al. (2020) using herbicides of different action mechanisms found similar results to those reported in the present work.

After the results obtained for the levels of phytotoxicity and the effects of herbicides on the grain yield components of wheat, the treatments with pyroxsulam, metsulfuron-methyl, 2,4-D, saflufenacil, bentazon, carfentrazone-ethyl, and [sulfentrazone+diuron], can be used in the culture, even if some of these do not present registrations for use. However, other studies similar to this one need to be conducted to indicate the products with greater safety, especially those that do not have a recommendation and registration for use in the culture of wheat.

**EXPERIMENT II - Evaluation of the efficacy of herbicides applied in wheat to control ryegrass and turnip rape.**

All variables showed significant effects except for the treatments on thousand-grain weight (Tables 4, 5, and 6).

Table 4. Control of ryegrass (*Lolium multiflorum*) infesting the wheat cultivar TBIO Sinuelo as a function of herbicide application. UFFS, Erechim/RS, 2018.

| Treatments | Control of ryegrass (%) | | | |
|---|---|---|---|---|
| | 7 DAT[1] | 14 DAT | 21 DAT | 28 DAT |
| Control weeded | 100.00 a[2] | 100.00 a | 100.00 a | 100.00 a |
| Control infested | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| Iodosulfuron | 22.50 d | 70.75 c | 60.00 c | 60.00 c |
| Pyroxsulam | 27.50 c | 78.75 b | 78.25 b | 51.25 d |
| Metsulfuron-methyl | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| 2,4-D | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| Clodinafope-propargil | 50.00 b | 93.75 a | 100.00 a | 91.25 b |
| [Bentazon+imazamox] | 0.00 e | 51.25 d | 29.00 d | 30.00 f |
| Saflufenacil | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| Bentazon | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| Carfentrazone-ethyl | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| Imazamox | 30.00 c | 55.00 d | 28.75 d | 42.50 e |
| Pendimethalin | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| [Sulfentrazone+diuron] | 0.00 e | 0.00 e | 0.00 e | 0.00 g |
| C.V. (%) | 20.05 | 19.56 | 2.47 | 19.17 |

[1] DAT: Days after treatment application. [2] Means followed by the same lowercase letters in the column do not differ by the Scott-Knott test at 5% probability.

The herbicide clodinafop-propargyl showed the highest efficacy on ryegrass in all control evaluations from 7 to 28 DAT (Table 4). Because the ryegrass in the experimental area showed no resistance to ACCase inhibitor herbicides, in addition to the high efficacy that this product presents when used on this weed, as already found elsewhere in the state of Rio Grande do Sul (HEAP 2021). Similarly, Trezzi et al. (2007), when working with herbicides in post-emergence wheat culture, found ryegrass control above 80% when using clodinafop-propargyl.

It was observed that the herbicides iodosulfuron, pyroxsulam, [bentazon + imazamox], and imazamox from 7 to 28 DAT showed low control of ryegrass compared with the weeded witness and the herbicide clodinafop-propargyl. However, the treatments with metsulfuron-methyl, 2,4-D, saflufenacil, bentazon, carfentrazone-ethyl and the formulated mixture of [sulfentrazone+diuron] (Table 4) were superior to the infested control. Ryegrass has reported resistance to ALS inhibitor herbicides (MARIANI et al. 2015), which may have occurred in the present study. On the other hand, with the use of pyroxsulam (GALON et al. 2014; ZOBIOLE et al. 2018) or iodosulfuron and [imazethapyr + imazapic] (GALON et al. 2014) found the best ryegrass controls, equivalent to the weeded witness, probably because the biotype used in these trials present susceptibility to the respective herbicides.

Table 5. Control of turnip (*Raphanus raphanistrum*) weeding of the wheat cultivar TBIO Sinuelo as a function of herbicide application. UFFS, Erechim/RS, 2018.

| Treatments | Control of turnip (%) | | | |
|---|---|---|---|---|
| | 07 DAT[1] | 14 DAT | 21 DAT | 28 DAT |
| Control weeded | 100.00 a[2] | 100.00 a | 100.00 a | 100.00 a |
| Control infested | 0.00 g | 0.00 d | 0.00 d | 0.00 d |
| Iodosulfuron | 43.75 e | 91.75 c | 99.75 a | 100.00 a |
| Pyroxsulam | 45.25 e | 98.00 b | 100.00 a | 100.00 a |
| Metsulfuron-methyl | 43.75 e | 98.75 a | 100.00 a | 100.00 a |
| 2,4-D | 66.25 d | 98.00 b | 100.00 a | 100.00 a |
| Clodinafope-propargil | 0.00 g | 0.00 d | 0.00 d | 0.00 d |
| [Bentazon+imazamox] | 67.50 d | 97.00 b | 93.50 b | 92.00 b |
| Saflufenacil | 80.75 c | 99.00 a | 100.00 a | 97.25 a |
| Bentazon | 85.75 b | 96.25 b | 93.75 b | 92.00 b |
| Carfentrazone-ethyl | 75.75 c | 99.25 a | 100.00 a | 100.00 a |
| Imazamox | 41.25 e | 91.50 c | 83.00 c | 83.00 c |
| Pendimethalin | 0.00 g | 0.00 d | 0.00 d | 0.00 d |
| [Sulfentrazone+diuron] | 0.00 f | 0.00 d | 0.00 d | 0.00 d |
| C.V. (%) | 15.40 | 1.97 | 1.21 | 2.98 |

[1] DAT: Days after treatment application. [2] Means followed by the same lowercase letters in the column do not differ by the Scott-Knott test at 5% probability.

The herbicides metsulfuron-methyl, 2,4-D, saflufenacil, bentazon, and carfentrazone-ethyl are registered and recommended for the control of dicot weeds in crops (AGROFIT 2021), not necessarily wheat, and this study is investigative in the sense of new alternatives for the management of weeds in this crop, especially for cases in which the species showed resistance to herbicides in use in crops. On the other hand, the formulated mixture of [sulfentrazone+diuron] is not recommended for ryegrass control (AGROFIT 2021), and has not shown efficacy on the weed.

Only the herbicide clodinafop-propargyl showed ryegrass control greater than 80%, this percentage being the minimum value required for a given herbicide to be recommended for weed control (OLIVEIRA et al. 2009). However, this recommendation becomes worrisome because ryegrass is very competitive with winter crops and still presents resistance to several mechanisms of action, such as ALS, ACCase, and EPSPs (ROMAN et al. 2004; VARGAS et al. 2013; MARIANI et al. 2015). GALON et al. (2019) observed that the occurrence of 1 plant $m^{-2}$ of ryegrass causes average grain yield losses of 0.30%, in the wheat cultivars TBIO Alvorada, BRS 327, BRS 328, BRS Marcante, and TBIO Pioneiro. In this study, the density of infestation was 40 ryegrass plants $m^{-2}$, if there is 80% control left in the field 8 plants $m^{-2}$ which would cause a loss of 2.4% or 55 kg $ha^{-1}$ taking into account the grain yield of the witness capped wheat cultivar TBIO Sinuelo.

To turnip control, at 7 DAT, it was observed that this was greater when bentazon was applied, followed by saflufenacil and carfentrazone-ethyl. However, all these treatments were below the control with weeding (Table 5). The other treatments showed low rates of turnip control, being higher only than the infested control. In the study by MICHELON et al. (2021) using the herbicides iodosulfuron and pyrosulam for turnip control, the efficacy rates at 7 DAT were lower and increased as the evaluation time passed. It is noteworthy, however, that clodinafop-propargyl, pendimethalin, and [sulfentrazone+diuron] are not registered and recommended for turnip control (AGROFIT 2021), so they showed no effect or control on the weed from 7 to 28 DAT (Table 5).

The results show that the herbicides metsulfuron-methyl, saflufenacil, and carfentrazone-ethyl showed the best turnip controls at 14 DAT, being statistically equal to the capped witness (Table 5). Iodosulfuron, pyroxsulam, 2,4-D, [bentazon+imazamox], bentazon and imazamox, despite being statistically inferior to the weeded witness, and to the herbicides metsulfuron-methyl, saflufenacil and carfentrazone-ethyl showed control above 90% and can be recommended for the management of turnip weeds in wheat.

Table 6. Effect of herbicides on components of grain yield, ears length (ears length - cm), full-grain, sterile grain, thousand-grain weight (PMG - g), hectoliter weight (PH - kg $hl^{-1}$), and grain yield (Prod. - kg $ha^{-1}$) of the wheat cultivar TBIO Sinuelo, 2018 crop. UFFS, Erechim/RS.

| Treatments | Wheat grain yield components | | | | | |
|---|---|---|---|---|---|---|
| | Ears length (cm) | Full grain | Sterile grain | PMG (g) | PH (kg $hl^{-1}$) | Prod. (kg $ha^{-1}$) |
| Control weeded | 7.55 a[1] | 27.50 c | 7.25 a | 31.31[ns] | 76.75 a | 2286.49 b |
| Control infested | 6.90 b | 25.75 c | 2.75 b | 31.13 | 70.00 b | 186.77 f |
| Iodosulfuron | 7.35 a | 34.75 a | 1.00 b | 29.86 | 71.75 b | 1846.03 c |
| Pyroxsulam | 7.78 a | 36.00 a | 2.00 b | 31.11 | 73.00 a | 2651.34 a |
| Metsulfuron-methyl | 6.95 b | 28.00 c | 1.75 b | 29.21 | 71.75 b | 1395.97 d |
| 2,4-D | 7.23 a | 33.50 a | 2.00 b | 30.40 | 70.75 b | 621.46 e |
| Clodinafope-propargil | 6.60 b | 26.50 c | 2.25 b | 31.48 | 75.00 a | 450.14 e |
| [Bentazon+imazamox] | 6.55 b | 35.75 a | 3.25 b | 30.68 | 73.00 a | 806.60 e |
| Saflufenacil | 7.75 a | 35.25 a | 2.00 b | 27.95 | 70.75 b | 551.30 e |
| Bentazon | 7.10 a | 31.25 b | 2.50 b | 29.31 | 73.50 a | 503.11 e |
| Carfentrazone-ethyl | 7.40 a | 31.00 b | 2.75 b | 31.37 | 73.00 a | 666.18 e |
| Imazamox | 7.65 a | 31.00 b | 3.50 b | 31.38 | 73.50 a | 1226.96 d |
| Pendimethalin | 6.78 b | 22.25 d | 1.75 b | 32.65 | 69.25 c | 566.02 e |
| [Sulfentrazone+diuron] | 7.40 a | 30.50 b | 2.50 b | 31.36 | 73.50 a | 549.17 e |
| C.V. (%) | 4.51 | 8.42 | 40.66 | 6.92 | 2.78 | 16.76 |

[1] Means followed by the same lower case letters in the column do not differ by the Scott-Knott test at 5% probability. [ns] not significant at 5% error probability.

The herbicides iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, saflufenacil, and carfentrazone-ethyl showed higher control efficacy of turnip at 21 DAT (Table 5). These treatments showed control equal to or greater than the weeded witness and maintained levels at 14 and 21 DAT. Bentazon+imazamox and bentazon, despite showing control greater than 92% (21 and 28 DAT), were below the control with weeding and the herbicide treatments that were equal to it.

As previously reported, the ALS inhibitor herbicides demonstrate the control effect later when compared to other products, it was observed for turnip control that the highest control rates were found from 14 DAT (Table 5). Furthermore, regarding turnip control, the biotype used in the experiment shows sensitivity to ALS inhibitor herbicides, since studies by PANDOLFO et al. (2013) and COSTA & RIZZARDI (2014) report the existence of turnip (*Raphanus raphanistrum* and *R. sativus*) with resistance to this mechanism in winter crops in Argentina and the Rio Grande do Sul.

The infested control and the herbicides metsulfuron-methyl, clodinafop-propargyl, [bentazon+imazamox], and pendimethalin showed shorter cob length (Table 6). This is due to the competition that turnip and ryegrass caused when these treatments were applied for weed control (Tables 4 and 5). The other herbicide treatments matched the weeded control with the longest cob lengths. Results found by MAHMOOD et al. (2013) demonstrate that the use of the herbicide [pinoxaden+cloquintocet-mexyl] positively affected the length of cobs, being superior to the infested witness and in some cases the application of clodinafop-propargyl, fenoxaprop-p-ethyl, and [iodosulfuron+mesosulfuron] demonstrate the negative effect, being only superior to the infested witness. ZACARYYIA et al. (2013), studying integrated weed management strategies reported that herbicides significantly affected growth and yield components, including wheat ear length.

The herbicide pyroxsulam showed the highest number of filled grains, followed by [bentazon+imazamox], saflufenacil, iodosulfuron, and 2,4-D, (Table 6). On the other hand, the lowest value was obtained in the treatment with pendimethalin with 13 fewer full grains per ear compared to pyroxsulam, which was the best treatment. The other treatments, including the weeded and infested control, were in intermediate levels. BARI et al. (2020) found the highest number of grains per ear in herbicide application and manual weeding treatments.

The number of sterile grains in the weeded control was the one with the highest number, statistically different from all other treatments (Table 6). This may be related to soil disturbance where the evapotranspiration of the crop increases. Thus there is less water availability for grain filling of the crop. FORTE et al. (2018) reported that in the no-till system, the straw is desirable because it reduces the evaporation of water from the soil, maintaining moisture and reducing the negative effects of the absence of cover.

The treatments did not differ statistically for the variable of thousand-grain weight (MCW) (Table 6). This fact may be related to phytotoxicity, inefficiency, or competition factors, varying according to the treatments used. Data found by BARI et al. (2020) when evaluating the use of herbicides in wheat, found that they did not show significance for the variable PMG, but showed the lowest weights in the infested control, and higher values when the herbicides clodinafop-propargyl, tribenuron+fluroxypyr+clopyralid, bromoxynil+MCPA, fenoxaprop-p-ethyl, fluroxypyr, pinoxaden+cloquintocet-mexyl, tribenuron-methyl+metsulfuron-methyl, and mesosulfuron+iodosulfuran, or with the manual weeding method. The application of pyroxsulam and clodinafop-propargyl showed higher PMG when used in weed management of wheat cultivar BRS 264 (OLIVEIRA 2019).

Only the herbicide applied pre-emergence, pendimethalin differed statistically from the weeded and infested witnesses, showing the lowest hectolitre weight (HW) (Table 6). The weeded control was statistically similar to pyroxsulam, clodinafop-propargyl, [bentazon+imazamox], bentazon, carfentrazone-ethyl, imazamox and [sulfentrazone+diuron]. The other treatments presented intermediate results, this may be related to the low control rates of ryegrass and turnip raising competition with wheat and the high phytotoxicity rates that varied according to each treatment, as previously reported.

The herbicide that maintained the highest level of productivity of the wheat cultivar TBIO Sinuelo differing statistically from all other treatments was pyroxsulam, being superior even to the weeded witness (Table 6). Subsequently, iodosulfuron, metsulfuron-methyl, and imazamox were the ones that showed higher yields than the infested control and the other treatments. Similar results in the use of herbicides with the variable grain yield were also found by OLIVEIRA (2019).

The low yields of some treatments may be linked to the reduced levels of control of ryegrass or turnip or even present low selectivity to the wheat cultivar TBIO Sinuelo. However, in general, all the components of grain yield were positively related to pyroxsulam and the weeded witness, that is, the length of ears, number of full grains, number of sterile grains, thousand-grain weight, hectoliter weight, and grain yield for these two treatments was higher than the others evaluated (Table 6). These results corroborate those found by GALON et al. (2015) when evaluating herbicides in the control of weeds in wheat, which ineffective found that pyroxsulam was among the best treatments evaluated when applied to the cultivars TBIO Pioneiro and TBIO Quartzo.

The treatment influenced the grain yield of wheat applied, where the best results were found using pyroxsulam, followed by the weeded control, which was on average 92.96 and 91.84% higher than the infested control, respectively, which showed the lowest yield (Table 6). The low grain yield of the infested witness reinforces the importance of adequate weed management so that the crop can express its maximum productive potential. The use of pyroxsulam showed better productivity than the weeded witness, a fact already reported by BASSO et al. (2018) since the use of weeding can harm the crop plants, besides the regrowth of weeds by the occurrence of rain or even not being effective in the sowing line of the crop.

The herbicides imazamox and [bentazon + imazamox] showed the highest percentages of phytotoxicity for the wheat cultivar TBIO Sinuelo (Table 2), due to the high injury or low control of weeds, especially ryegrass, these showed the lowest grain yields in the two experiments in which they were evaluated (Tables 2 and 6). This fact was demonstrated by OLIVEIRA (2019) when using the commercial mixture [bentazon + imazamox] that caused high phytotoxicity when applied to wheat, causing even plant death.

With the results found in the two experiments, it is clear that if no control measures are adopted, the losses related to grain yield components occur irreversibly. Thus, it becomes necessary to search for viable and efficient alternatives that are also selective to wheat.

For wheat, few studies have evaluated the selectivity and control efficacy of these herbicides and the effects on the components of grain yield of the crop separately. MICHELON et al. (2021) evaluated the control of weeds and phytotoxicity caused by different herbicides applied to wheat cultivars, TBIO Toruk and TBIO Audaz, together. The authors' control of turnip and ryegrass was 75% and 85% when applying pyroxsulam and pinoxaden, respectively. The phytotoxicity was less than 3% for the two cultivars, regardless of the product used in the experiment. GALON et al. (2015), when studying the phytotoxicity and weed control with the use of several herbicides in a single experiment, observed that [imazethapyr + imazapic], clomazone, and [imazapic + imazapyr] showed the greatest injury to wheat and the best control of turnip and ryegrass. The same authors also report that iodosulfuron showed the least negative influence on grain yield components of the cultivars TBIO Quartzo and TBIO Pioneiro, which is similar in parts to the results found in the present research.

## CONCLUSION

The herbicides that caused the greatest phytotoxicities to the wheat cultivar TBIO Sinuelo were imazamox and the commercial mixture [bentazon + imazamox].

The herbicide clodinafop-propargyl demonstrated greater ryegrass control, while the herbicides iodosulfuron, pyroxsulam, metsulfuron-methyl, 2,4-D, saflufenacil, and carfentrazone-ethyl resulted in greater efficacy for turnip control.

Pyroxsulam was the treatment that showed the best results for all-grain yield components in both experiments (selectivity and efficacy), especially yield.

The loss in wheat grain yield is higher than 90% if no weed control method is adopted, either with weeding or the use of herbicides.

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