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ADDITION OF PROTOX INHIBITORS HERBICIDES TO GLYPHOSATE IN THE DESICCATION OF *Urochloa brizantha* BRS "Piatã"

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Resumo

Plantas do gênero *Urochloa* são adotadas como cultura de cobertura e a dessecação é fundamental para implantação das culturas subsequentes. Aqui, avaliamos a dessecação de *Urochloa brizantha* BRS "Piatã" por meio do uso de glifosato associado a diferentes inibidores da protoporfirinogênio oxidase (PROTOX). Os tratamentos foram dispostos em esquema fatorial (2x5+1), sendo constituídos por duas doses de glifosato de 900 e 1800 g e.a. ha^{-1} (D1 e D2) associado ou não à carfentrazone-ethyl (20 g i.a. ha^{-1}), flumioxazin (20 g i.a. ha^{-1}), saflufenacil (35 g i.a. ha^{-1}) e tiafenacil (70 g i.a. ha^{-1}), além do tratamento controle (sem herbicidas). O estudo foi conduzido em Alvorada do Sul (ALV) e Londrina (LDN), ambos no estado do Paraná, Brasil. Sete dias após a aplicação dos tratamentos (DAT) o índice de clorofilas foi mensurado, enquanto a porcentagem de injúria tecidual foi avaliada pela escala visual (0-100) aos 7, 14, 21 e 28 DAT. Ao final do experimento foram mensuradas a massa fresca e seca da parte aérea, e porcentagem de água (%H_2O) no tecido. Para o experimento em ALV, glifosato D2 + flumioxazin atingiu 68,7% de injúria. A porcentagem de água foi reduzida em todos os tratamentos em relação ao controle, sendo que a D2 propiciou maior redução. Por outro lado, em LDN, não foi observada diferença entre os tratamentos com ou sem inibidores da PROTOX. A porcentagem de água confirmou o resultado obtido pela escala visual, em que a D2 de glifosato resultou em média 90,5% de controle aos 28 DAA, 9,5% maior que a D1. Em ambos os experimentos, a mistura de glifosato com flumioxazin merece destaque pois acelerou a cinética de mortalidade das plantas. A D2 foi mais eficaz em controlar as plantas (em média 8,5% maior que a D1).

Palavras-chaves: capim-braquiária; controle de plantas daninhas; flumioxazina; misturas de herbicidas; protoporfirinogênio oxidase.

Adição de herbicidas inibidores da Protox ao glifosato na dessecação de *Urochloa brizantha* BRS "Piatã"

Abstract

Plants of the genus *Urochloa* are adopted as cover crops, and desiccation is essential for implementing subsequent crops. Here, we evaluated the desiccation of *Urochloa brizantha* BRS "Piatã" using glyphosate associated with different protoporphyrinogen oxidase inhibitors (PROTOX). The treatments were arranged in a factorial scheme (2x5+1), consisting of two glyphosate doses of 900 and 1800 g a.e. ha^{-1} (D1 and D2), associated or not with carfentrazone-ethyl (20 g a.i. ha^{-1}), flumioxazin (20 g a.i. ha^{-1}), saflufenacil (35 g a.i. ha^{-1}), and tiafenacil (70 g a.i. ha^{-1}), in addition to the control treatment (without herbicides). The study was conducted in Alvorada do Sul (ALV) and Londrina (LDN), both in Paraná state, Brazil. Seven days after application (DAA), the chlorophyll index was measured. The percentage of tissue injury was assessed by the visual scale (0-100) at 7, 14, 21, and 28 DAA. At the end of the experiment, the fresh and dry shoot mass and the percentage of water (%H_2O) in the tissue were measured. For the experiment in ALV, glyphosate D2 + flumioxazin reached 68.7% of injury. The percentage was reduced in all treatments in relation to the control, with D2 providing the greatest reduction. On the other hand, in LDN, no difference was observed between treatments with or without PROTOX-inhibitors. The percentage confirmed the result obtained by the visual scale, in which glyphosate at D2 resulted in an average of 90.5% control at 28 DAA, 9.5% greater than D1. In both experiments, the mixture of glyphosate and flumioxazin deserves to be highlighted as it accelerated the kinetics of plant mortality. D2 was more effective in controlling the plants (on average 8.5% greater than D1).

Key-words: signal grass; weed control; flumioxazin; herbicide mixtures; protoporphyrinogen oxidase.

Introduction

The benefits that the no-till system (NTS) has brought to the production environment are evidenced by its widespread use. Principles have been established for successful implementation of NTS, such as minimum soil disturbance, permanent cover, and crop rotation (Possamai *et al.*, 2022), and different species have been used to ensure permanent soil cover, with emphasis on those of the genus *Urochloa*.

These species stand out for their ability in nutrient cycling (Burin, 2017) and improving the biochemical and physical attributes of the soil (Santos *et al.*, 2015), in addition to their versatility, as they are even used in consortium systems (Alves *et al.*, 2013). However, a challenge that has arisen with the use of these species is the quality of pre-planting desiccation, since this is an important step in ensuring the good development of the subsequent crop (Santos *et al.*, 2022).

Herbicides are used to effect desiccation, among them glyphosate, launched on the market in 1974, that is currently the most widely used chemical molecule in agriculture. Glyphosate is a non-selective, broad-spectrum, post-emergent herbicide. Its action occurs by inhibiting the enzyme EPSPS (5-enolpyruvylshikimate-3-phosphate synthase), responsible for the synthesis of the amino acids tyrosine, phenylalanine, and tryptophan (Zulet-González *et al.*, 2020). Understanding the glyphosate molecule and its interactions with other herbicides is important to optimize its use. Frequently, the combination of different active ingredients is used to optimize the operation and action of the herbicides (Gazziero, 2015; Costa *et al.*, 2019; Quadros *et al.*, 2020). But it is important to know the effects of these mixtures, so that they do not harm the control of the target species (Albrecht *et al.*, 2023).

The literature reports the mixture of glyphosate with different herbicides, emphasizing mixtures with protoporphyrinogen oxidase inhibitors (PROTOX). These herbicides cause the accumulation of protoporphyrinogen IX, which is leaked out of the chloroplast membranes (Barker *et al.*, 2023). Outside the organelle, its conversion to protoporphyrin IX occurs, even without the presence of the enzyme. In the presence of light and oxygen, protoporphyrin IX results in the production of reactive oxygen species (ROS), which cause membrane damage and cell necrosis (Duke *et al.*, 1990; Takano *et al.*, 2020).

The active ingredients belonging to this mechanism of action present some peculiarities linked to each herbicide, such as a pre- or post-emergent effect, mobility in plants, and also selectivity (Dalazen *et al.*, 2015; Piasecki, 2024). Agostineto *et al.* (2016) found increased control of *Ipomoea hederifolia* when mixing saflufenacil and carfentrazone-ethyl with glyphosate. In the control of *Ipomea triloba* and *Digitaria insularis*, the mixture of glyphosate and saflufenacil was considered additive (Presoto *et al.*, 2020). In *Conyza*, Dalazen *et al.* (2015) observed a synergistic effect in the mixture of glyphosate and saflufenacil.

However, it is important to understand the effect of these mixtures on other species, such as those belonging to the genus *Urochloa*. Little is known about the effect of PROTOX inhibitors mixed with glyphosate on *Poaceae*. Therefore, the aim of the current study was to evaluate the effects of adding five different PROTOX inhibitors herbicides to glyphosate for desiccation of *U. brizantha* "BRS Piatã". The following hypotheses were tested: **(1)** the combination of glyphosate with PROTOX inhibitors herbicides accelerates mortality of *U. brizantha* "BRS Piatã"; **(2)** some PROTOX inhibitors herbicides intended for predominant control of eudicotyledonous weeds may delay the action of glyphosate on *U. brizantha* "BRS Piatã"; **(3)** increasing the dose of glyphosate results in better and faster mortality of *U. brizantha* "BRS Piatã".

Material and methods

Two field experiments were conducted in the municipalities of Alvorada do Sul (ALV) and Londrina (LDN), both in the state of Paraná (PR), Brazil, from September to October 2023 and

January to March 2024, respectively. In ALV, the study was conducted at the Sítio Cerro Alegre property (22º 43'26"S 51º17'09"W, altitude: 419 m), in soil characterized as eutroferric Red Latosol. The experiment was conducted in an area of *U. brizantha* "BRS Piatã" cultivated in consortium with corn. Corn cultivation took place from March to August of 2023, with the consortium being implemented at the time of sowing the cereal. The grass sowing methodology used was surface sowing in synchrony with corn, with a third sowing box system coupled to the precision seeder, with a spacing of 45 cm between rows, at a sowing rate of 12 kg ha^{-1}. In LDN, the study was conducted at the School Farm of the State University of Londrina (FAZESC-UEL) (26º20'33"S 51º12'41"W, altitude: 566 m), in soil characterized as eutroferric Red Latosol, in a single cultivation area of *U. brizantha* "BRS Piatã". For sowing, a seeder was used with a spacing of 19 cm between rows, at a rate of 12 kg ha^{-1}. The soil was prepared before sowing, in November 2023.

Figure 1 shows the water balance for ALV. Precipitation data (mm) were collected at the experimental site using a rain gauge. Evapotranspiration data (ETP) were kindly provided by Embrapa-Soja (Londrina-PR) (Sibaldelli *et al*., 2023), and are based on the method of Thornthwaite and Mather (1955) and water storage capacity (WSC = 75 mm).

Figure 1. Ten-day water balance for Alvorada do Sul – PR. EXC = Excess. DEF = Deficit. The arrows indicate the beginning and end of the experiment, while the star indicates the corn harvest.

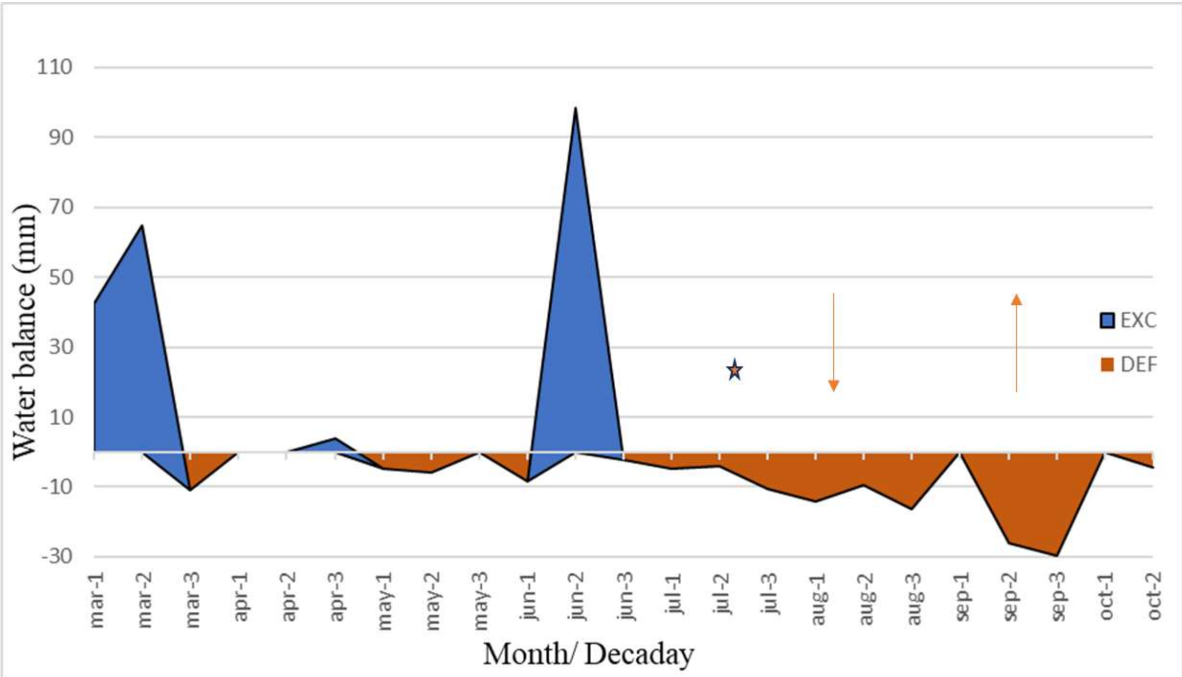
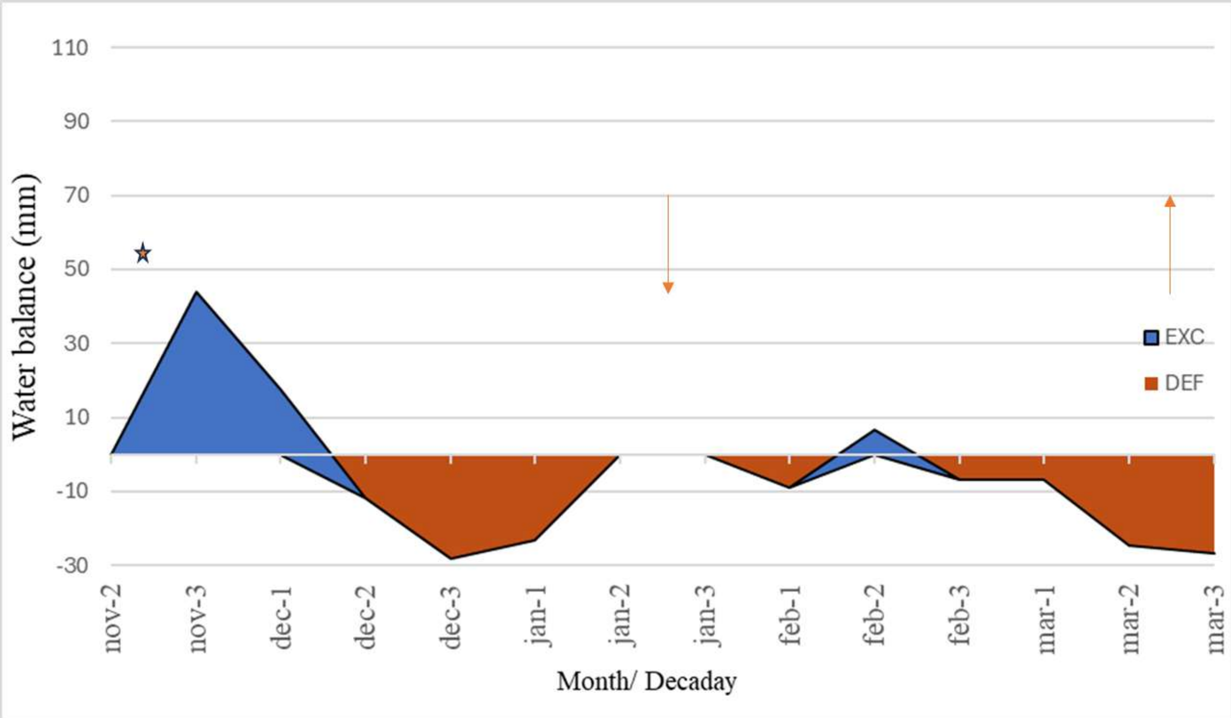


Figure 2 presents the water balance for Londrina. Precipitation data (mm) were kindly provided by the Paraná Rural Development Institute (IDR-PR), collected by a local meteorological station. Evapotranspiration data (ETP) were kindly provided by Embrapa-Soja (Londrina-PR) (Sibaldelli *et al.*, 2023), and are based on the Thornthwaite and Mather method (1955) and water storage capacity (WSC = 75 mm).

Figure 2. Water balance for the School Farm of the State University of Londrina (FAZESC-UEL). EXC = Excess. DEF = Deficit. The arrows indicate the beginning and end of the experiment, while the star indicates the sowing of the studied species.



The treatments were arranged in a randomized block design, with four replications (3.2 x 5.0 m plots), in a 2x5+1 factorial scheme, with two doses of glyphosate (Crucial 540 g a.e. Sumitomo Chemical): 900 and 1800 g a.e. ha^{-1}; and five PROTOX inhibitors: absence, carfentrazone-ethyl (20 g a.i. ha^{-1}) (Aurora® 400 EC FMC Chemical), flumioxazin (25 g a.i. ha^{-1}) (Flumyzin 500 SC Sumitomo Chemical), saflufenacil (35 g a.i. ha^{-1}) (Heat® Basf), and tiafenacil (70 g a.i. ha^{-1}) (Terrad'or 339 SC ISK – Biosciences), plus an additional control, totaling 11 treatments.

The treatments were applied using a CO_2 pressurized backpack sprayer with a 3 m spray boom and six ADI 110015 spray tips. The application was performed at a rate of 110 L ha^{-1}, under ideal temperature and humidity conditions at the time of application. There was no dust on the leaves and the absence of precipitation was ensured for six hours after the treatments. In both locations, the water used came from the same source (Londrina-PR water treatment system), with hydrogen potential - pH (5.3) determined with the aid of a benchtop pH meter (Fisher Scientific Accumet AB150, Waltham, MA, US). Electrical conductivity (0.17 mS cm^{-1}) was determined using a conductivity meter (HANNA instruments, HI 8732 Portable EC, TDS, Park East Drive, Woonsocket, RI, EUA).

The application of the ALV treatments was performed 40 days after the corn harvest, when the plants of *U. brizantha* were approximately 40 cm tall and had a fresh mass of around 9,500 kg ha^{-1}. In LDN, the plants were approximately 95 cm tall and had a fresh mass of around 30,000 kg ha^{-1} at the time of application.

Seven days after application of the treatments (DAA), leaf analysis of the chlorophyll index was performed using a chlorophyll meter (atLEAF, model CHL BLUE). It was decided to perform the analysis on a fully expanded leaf directly exposed to the application. The equipment was configured to measure the average chlorophyll index of the chosen leaf. Two samples were taken per plot. In the period of 7, 14, 21, and 28 DAA, visual control analysis was performed using the scale proposed by Frans *et al.* (1986), from zero to 100, where 100 represents total death of the plants.

At the end of the experiment, with the aid of a 40 x 40 cm sampling frame, the fresh mass of the aerial part (FM) of the plants was collected, in two samples per experimental unit. Subsequently, the samples were dried in a forced air circulation oven at 60 ºC, until reaching constant dry mass (DM). Using the FM and DM values, the percentage of water (%H_2O) was measured, expressed based on the FM, as established by Guimarães and Stone (2008). The evaluations were carried out in the useful area of each experimental unit, excluding 0.5 m from each side.

The experiments were evaluated separately due to differences in the described characteristics of the experimental sites. The data were submitted to analysis of variance (ANOVA) using the F test and, when significant, the treatment means were compared using the Dunnett test ($p < 0.05$). In addition, herbicide treatments were also subjected to ANOVA and, when significant, the means were compared by Tukey's test ($p < 0.05$). The data were transformed as necessary to meet the ANOVA assumptions, using the $\sqrt{X}$ transformation.

Results and discussion

The results of the experiment performed in Alvorada do Sul – PR (ALV) demonstrate anticipatory effects of injury symptoms with the addition of flumioxazin, regardless of the dose of glyphosate. Treatments with flumioxazin achieved a higher percentage of visual injury than glyphosate alone and mixtures with other PROTOX inhibitors at 7 and 14 DAT (data not shown). The chlorophyll index (Table 1) corroborates the injury results, since the treatments with flumioxazin and tiafenacil, regardless of the glyphosate dose, were the only ones that differed from the control treatment. Carfentrazone-ethyl, in turn, had a lower capacity to reduce the chlorophyll index than the herbicides flumioxazin and tiafenacil. Carfentrazone-ethyl, at 7 DAA, resulted in less visual injury than glyphosate alone, but this effect did not persist in the subsequent evaluations.

Regarding the evaluations at 21 (data not shown) and 28 DAA (Table 1), flumioxazin resulted in 11.1% more injury than glyphosate alone; however, the visual injury scale revealed a percentage less than 80%, that is, unsatisfactory. In all periods evaluated, the dose of 1,800 g a.e. ha^{-1}, regardless of the addition of PROTOX inhibitors, resulted in a higher percentage of injury, by an average of 4.8% among the four periods evaluated. The water percentage (Table 2) was reduced by the treatments compared to the control, in accordance with the visual assessment, in which the higher dose of glyphosate was more effective in dehydrating the plants. These results provide evidence of the need for a higher dose for desiccation in the situations described, since the lower water percentage is a result of the action of the herbicide.

Table 1. Chlorophyll index 7 days after application of treatments (DAA) and percentage of visual injury at 28 DAA of plants of *Urochloa brizantha* BRS "Piatã" subjected to application of glyphosate in two doses, in the presence and absence of different PROTOX inhibitors, for the experiment performed in Alvorada do Sul – PR (ALV).

Parameter	**Chlorophyll index**			**Visual Injury (%) 28 DAA**		
Protox inhibitor	**Glyphosate (g a.e. ha^{-1})**			**Glyphosate (g a.e. ha^{-1})**		
	900	1,800	Mean	900	1,800	Mean
Absence	35.2	33.7	34.5 ab	47.5*	57.5*	52.5 b
Carfentrazone-ethyl	35.5	34.6	35.1 a	48.7*	56.2*	52.5 b
Flumioxazin	29.9*	29.3*	29.7 b	60.0*	68.7*	64.3 a
Saflufenacil	34.2	33.2	33.7 ab	50.0*	58.7*	54.3 b
Tiafenacil	29.9*	29.5*	29.7 b	51.2*	55.0*	53.1 b
Mean	32.9 A	32.1 A		51.5 B	59.2 A	
Control	40.8			0		
C.V. (%)	5,5			4,2		

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other; lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * indicates that there was a difference in relation to the control according to Dunnett's test ($p < 0.05$). C.V. = Coefficient of variation (%). Glyphosate = Crucial 540 g a.e. (Sumitomo Chemical). Carfentrazone-ethyl (20 g a.i. ha^{-1}) (Aurora® 400 EC FMC Química), flumioxazin (25 g a.i. ha^{-1}) (Flumyzin 500 SC Sumitomo Chemical), saflufenacil (35 g a.i. ha^{-1}) (Heat® Basf), and tiafenacil (70 g a.i. ha^{-1}) (Terrad'or 339 SC ISK – Biosciences).

Table 2. Dry mass of aerial part (DM) and water percentage (%H_2O) of plants of *Urochloa brizantha* BRS "Piatã" subjected to application of glyphosate in two doses, in the presence and absence of different PROTOX inhibitors, for the experiment performed in Alvorada do Sul – PR (ALV).

Parameter	**DM (g^-)**					**%H_2O**				
Protox inhibitor	**Glyphosate (g a.e. ha^{-1})**					**Glyphosate (g a.e. ha^{-1})**				
	900	1,800	Mean			900	1,800		Mean	
Absence	136.1	77.6	108.3	a		49.5*	36.8*		43.2	a
Carfentrazone-ethyl	149.4	109.7	129.5	a		49.1*	42.4*		45.8	a
Flumioxazin	131.2	125.1	128.2	a		48.9*	41.3*		45.1	a
Saflufenacil	125.4	104.8	115.1	a		51.3*	40.2*		45.8	a
Tiafenacil	144	113.8	128.9	a		48.4*	39.3*		43.8	a
Mean	137.8 A	106.2 B				49.4 A	40	B		
Control	117.1					61.6				
C.V (%)	16,4					5,1				

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other; lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * indicates that there was a difference in relation to the control according to Dunnett's test ($p < 0.05$). C.V. = Coefficient of variation (%). Glyphosate = Crucial 540 g a.e. (Sumitomo Chemical). Carfentrazone-ethyl (20 g a.i. ha^{-1}) (Aurora® 400 EC FMC Química), flumioxazin (25 g a.i. ha^{-1}) (Flumyzin 500 SC Sumitomo Chemical), saflufenacil (35 g a.i. ha^{-1}) (Heat® Basf), and tiafenacil (70 g a.i. ha^{-1}) (Terrad'or 339 SC ISK – Biosciences).

In turn, the experiment carried out in LDN demonstrated that, at 7 DAA, treatment with tiafenacil resulted in greater visual injury compared to treatments with carfentrazone-ethyl, saflufenacil, and glyphosate alone (Table 3). This result was not maintained in the other periods evaluated (data not shown). At 21 DAA, flumioxazin mixed with glyphosate presented an increased effect compared to saflufenacil, but the final evaluation at 28 DAA (Table 3) showed no difference between the different PROTOX-inhibiting herbicides or its absence. The control can be considered effective, due to the percentage of visual injury caused by the treatments (>80%).

The dose of 1,800 g a.e. ha^{-1} resulted in more effective control of the plants compared to the dose of 900 g a.e. ha^{-1}, as expected. This result highlights the importance of using the correct dose of glyphosate for desiccation. Regarding the chlorophyll index, there was no difference between the treatments, with only the treatment with tiafenacil differing from the control. For the fresh and dry masses, there was also no difference between the treatments. In turn, the Dunnett test revealed that all herbicide treatments were different from the control. The percentage of water corroborated the results of the visual evaluations, in which the highest dose resulted in a lower percentage of water in relation to the dose of 900 g a.e. ha^{-1} (Table 4).

Table 3. Percentage of visual injury at 7 and 28 days after application of treatments (DAA) of plants of *Urochloa brizantha* BRS "Piatã" subjected to application of glyphosate in two doses, in the presence and absence of different PROTOX inhibitors, for the experiment performed in Londrina (LDN).

Parameter	**Visual Injury (%) 7 DAA**					**Visual Injury (%) 28 DAA**				
	Glyphosate (g a.e. ha^{-1})					**Glyphosate (g a.e. ha^{-1})**				
Protox inhibitor	900		1,800		Mean	900		1,800		Mean
Absence	11.2		15.0*		13.1 b	83.7*		95.0*		89.3 a
Carfentrazone-ethyl	13.8		16.2*		15.0 b	81.5*		86.2*		83.8 a
Flumioxazin	17.5*		23.7*		20.6 ab	82.5*		95.0*		88.7 a
Saflufenacil	16.2*		12.5		14.3 b	78.7*		87.5*		83.1 a
Tiafenacil	23.7*		25.0*		24.3 a	78.7*		88.7*		83.7 a
Mean	16.4	B	18.5	A		81.0	B	90.5	A	
Control	0					0				
C.V. (%)	17.0					4,8				

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other; lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * indicates that there was a difference in relation to the control according to Dunnett's test ($p < 0.05$). C.V. = Coefficient of variation (%). Glyphosate = Crucial 540 g a.e. (Sumitomo Chemical). Carfentrazone-ethyl (20 g a.i. ha^{-1}) (Aurora® 400 EC FMC Química), flumioxazin (25 g a.i. ha^{-1}) (Flumyzin 500 SC Sumitomo Chemical), saflufenacil (35 g a.i. ha^{-1}) (Heat® Basf), and tiafenacil (70 g a.i. ha^{-1}) (Terrad'or 339 SC ISK – Biosciences).

Table 4. Dry mass of aerial part (DM) and percentage of water (%H_2O) of plants of *Urochloa brizantha* BRS "Piatã" subjected to application of glyphosate in two doses, in the presence and absence of different PROTOX inhibitors, for the experiment performed in Londrina (LDN).

Parameter	**DM (g⁻)**				**%H_2O**			
Protox inhibitor	**Glyphosate (g a.e. ha^{-1})**				**Glyphosate (g a.e. ha^{-1})**			
	900	1,800	Mean		900	1,800	Mean	
Absence	207.0*	251.2*	229.1	a	34.5*	24.4*	29.4	a
Carfentrazone-ethyl	288.0*	211.7*	249.8	a	33.9*	31.3*	32.6	a
Flumioxazin	215.8*	251.1*	233.4	a	32.7*	27.7*	30.2	a
Saflufenacil	218.7*	254.6*	236.6	a	40.7*	31.1*	35.9	a
Tiafenacil	243.8*	227.6*	235.7	a	39.6*	33.5*	36.5	a
Mean	234.6 A	239.2 A			36.3 A	29.6 B		
Control	2157.0				64.02			
C.V. (%)	11.0				8.6			

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other; lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * indicates that there was a difference in relation to the control according to Dunnett's test ($p < 0.05$). C.V. = Coefficient of variation (%). Glyphosate = Crucial 540 g a.e. (Sumitomo Chemical). Carfentrazone-ethyl (20 g a.i. ha^{-1}) (Aurora® 400 EC FMC Química), flumioxazin (25 g a.i. ha^{-1}) (Flumyzin 500 SC Sumitomo Chemical), saflufenacil (35 g a.i. ha^{-1}) (Heat® Basf), and tiafenacil (70 g a.i. ha^{-1}) (Terrad'or 339 SC ISK – Biosciences).

The current study demonstrates important results regarding the mixture of herbicides, mainly in relation to the mixture of glyphosate with flumioxazin, resulting in an increase in the speed of injury to *Urochloa brizantha* BRS "Piatã" (Figure 3). In *Paspalum maritimum* Trind, Tenório Filho *et al.* (2023) found that glyphosate in combination with flumioxazin increased the rate of injury in the species compared to the isolated use of the first herbicide. The interactions of glyphosate with other herbicides have been widely studied and reported. Many studies indicate that the mixture with other systemic herbicides favors the efficiency of glyphosate, while contact herbicides may impair its effect (Vidal *et al.*, 2016), since the rapid effect of contact herbicides through the accumulation of ROS can reduce the translocation of glyphosate, an effect also observed with other herbicides such as lactofen and fomesafen (Starke; Oliver, 1996; Norris *et al.*, 2001).

A difference was observed between the experimental sites, which can be explained by the grass development conditions at the sites. In the experiment in ALV, the intercropping system and the restricted water availability (Figure 1) during the development of the Piatã grass resulted in unsatisfactory control. At this location, treatments with flumioxazin resulted in a higher visual percentage of control even at 28 DAA, unlike the experiment in LDN, in which there was no difference between the different conditions with the PROTOX-inhibiting herbicides during this period.

PROTOX inhibitor herbicides are often used on difficult to control weeds, most of which are tolerant or resistant to glyphosate. Saflufenacil and tiafenacil are examples of herbicides used for controlling *Conyza* spp. (Dalazen *et al.*, 2015; Park *et al.*, 2018; Bornelli *et al.*, 2022; Duarte *et al.*, 2023), while carfentrazone-ethyl is used for the genera *Ipomea* and *Commelina* (Ronchi *et al.*, 2002; Werlang; Silva, 2002) and flumioxazin for *Spermacoce* (Lourenço *et al.*, 2021).

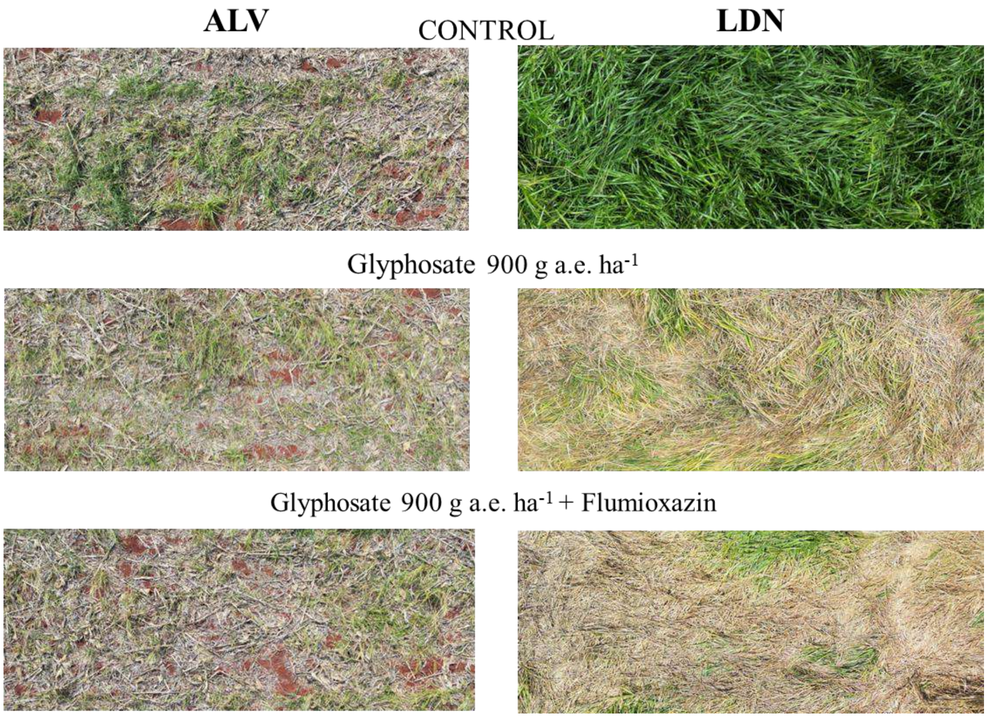
Werlang and Silva (2002) studied the effect of a mixture of glyphosate and carfentrazone-ethyl to control six weed species, among them, *Eleunise indica.* It was found that when the lowest dose of glyphosate was used (252 g a.e. ha^{-1}), there was an antagonistic effect, which was overcome when the mixture was performed at the highest dose (720 g a.e. ha^{-1}). Although this result was not repeated in the current study, a similar trend could be observed with saflufenacil, in evaluations at 14 DAA (data not shown) for the experiment performed in ALV.

Eubank *et al.* (2013) studied the effect of mixtures of glyphosate and saflufenacil on *C. canadensis* populations and found lower translocation of glyphosate when the herbicides were mixed, even though the mixture resulted in greater injury than the isolated use of glyphosate. This result may explain the lower injury caused by the combination of herbicides in our study due to the reduction in glyphosate translocation, since any damage to the systemic action of glyphosate directly impacts its efficiency (Bastiani *et al.*, 2021).

Among the PROTOX inhibitors evaluated in the current study, tiafenacil is the most recently launched on the market. In laboratory tests, tiafenacil was shown to be highly effective in inhibiting its target enzyme, as well as in controlling eudicotyledonous and grassy species (Park *et al.*, 2018). In the field, in the control of *D. insularis*, there was synergy when mixing with graminicides, in addition to the control of *Conyza* spp. (Duarte *et al.*, 2023).

During the desiccation stage, agricultural areas are affected by a combination of weed species, which means that it is necessary to use different herbicides for different target species, and it is extremely important that these mixtures do not harm weed control. The results of the current study demonstrate that the mixture of herbicides accelerates the effect of glyphosate. In practice, this may mean bringing forward the sowing of crops. Considering the succession system of soybeans followed by second-crop corn in consortium with *Urochloa* spp., bringing forward the sowing of the oilseed would also allow the sowing of the cereal within a more favorable season for its development and grain yield (Buso *et al.*, 2017).

Figure 3. Area image of plots of *Urochloa brizantha* BRS "Piatã", 21 days after application of treatments (DAA); Control; Glyphosate 900 g a.e. ha^{-1} and Glyphosate 900 g a.e. ha^{-1} + Flumioxazin 25 g a.i. ha^{-1}, in ALV – Alvorada do Sul – PR and LDN – Londrina – PR.



Conclusion

The current study demonstrates that flumioxazin accelerates the mortality kinetics of *Urochloa brizantha* BRS "Piatã" and may be an alternative to anticipate desiccation symptoms, creating opportunities to anticipate other field operations, such as sowing the next crop. The correct dose of glyphosate is essential for good control of the species. The combined use of glyphosate with the PROTOX inhibitors carfentrazone-ethyl, flumioxazin, saflufenacil, and tiafenacil can be used on Piatã grass without compromising the action of the glyphosate herbicide. Thus, these PROTOX-inhibiting herbicides can be used to control other weeds present in the area, tolerant or resistant to glyphosate, without compromising its action on *Urochloa brizantha* BRS "Piatã".

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