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Scientific Article

Herbicide selectivity for conventional maize hybrid

Seletividade de herbicidas para híbrido de milho convencional

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ABSTRACT - The cultivation of conventional maize in refuge areas is important for preserving *Bt* technology and serving specific markets with greater added value to the grains. Therefore, research aimed at chemical weed control must also continue to be directed to conventional maize hybrids. The objective was to evaluate the selectivity of herbicides applied in pre- and post-emergence of a conventional maize hybrid cultivated in the *Cerrado* biome of Brazil. Two field experiments were set up, one in summer and the other in second season. The treatments were composed of eleven herbicide treatments, whose doses are presented in g ha^{-1} of active ingredient: S-metolachlor (1,440), S-metolachlor (1,680), mesotrione + atrazine (115.2 + 2,000), mesotrione + atrazine (192 + 2,000), tembotrione + atrazine (75.6 + 2,000), tembotrione + atrazine (100.8 + 2,000), nicosulfuron + atrazine (16 + 2,000), nicosulfuron + atrazine (24 + 2,000), [mesotrione + atrazine] ([120 + 1,200]), sequential application of [mesotrione + atrazine] ([60 + 600]), atrazine (2,000), plus a weeded control. Regardless of the experiment, all herbicides applied pre- and post-emergence of maize led to low percentages of phytointoxication. In both experiments, none of the treatments caused reductions in crop stand, confirming the absence of plant mortality due to the application of herbicides. Plant tipping/lodging was seen in summer maize, with no treatment effect. Maize 100-grain mass and yield did not change as a result of the application of herbicides in pre- and post-emergence of the crop. All herbicide treatments evaluated showed selectivity for the conventional maize hybrid.

Keywords: Chemical control. Non-GMO. Weed. *Zea mays*.

RESUMO - O cultivo do milho convencional em áreas de refúgio é importante para preservação da tecnologia *Bt* e para atender mercados específicos com maior valor agregado aos grãos. Portanto, as pesquisas voltadas ao controle químico de plantas daninhas também devem continuar direcionadas aos híbridos convencionais de milho. O objetivo foi avaliar a seletividade de herbicidas aplicados em pré e pós-emergência de um híbrido convencional de milho cultivado no bioma Cerrado do Brasil. Foram instalados dois experimentos de campo, um na safra verão e outro segunda safra. Os tratamentos foram onze herbicidas, cujas doses são apresentadas em g ha^{-1} de ingrediente ativo: S-metolachlor (1.680), mesotrione + atrazine (115,2 + 2.000), mesotrione + atrazine (192 + 2.000), tembotrione + atrazine (75,6 + 2.000), tembotrione + atrazine (100,8 + 2.000), nicosulfuron + atrazine (16 + 2.000), nicosulfuron + atrazine (24 + 2.000), [mesotrione + atrazine] ([120 + 1.,200]), aplicação sequencial de [mesotrione + atrazine] ([60 + 600]), atrazine (2.000), mais testemunha capinada. Independentemente do experimento, todos os herbicidas aplicados pré e pós-emergência do milho proporcionaram baixos percentuais de fitointoxicação. Em ambos os experimentos nenhum dos tratamentos causou redução no estande, confirmando a ausência de mortalidade das plantas pela aplicação de herbicidas. O tombamento/acamamento das plantas foi observado no experimento realizado de verão e não observou efeito entre tratamentos. Massa de 100 grãos e produtividade do milho não alteraram em função da aplicação de herbicidas na pré e pós-emergência da cultura. Todos os tratamentos herbicidas avaliados apresentaram seletividade ao híbrido de milho convencional.

Palavras-chave: Controle químico. Não geneticamente modificado. Plantas daninhas. *Zea mays*.

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INTRODUCTION

Maize cultivation in Brazil has always been carried out in the summer season, but in the last decade the percentage of area cultivated with this cereal in the second season has increased (ALMEIDA et al., 2024). The area of second-season maize increased from 3,276,160 ha in 2003 to 15,987,924 ha in 2022 (IBGE, 2023). This change in the maize production system was possible due to the physiology of the plant because, as it is C4 type, with moderate tolerance to water deficit, it showed good adaptability to the climatic conditions occurring in this new cultivation period (CUNHA et al., 2019).

In addition, genetic improvement helped in this process, with the development of hybrids with high yield potential and stability among production environments. However, there are still major obstacles to obtaining higher yields, such as the occurrence of pests, diseases and weeds. Considering only weed interference, losses of up to 50% of maize yield have been reported when weed control practices are not adopted (SOLTANI et al., 2016).

Weeds, through the process of interference when coexisting with maize, reduce crop yield through competition for essential resources (water, nutrients, light, and physical space), allelopathy, in addition to imposing restrictions on mechanized harvesting of this crop (HELVIG et al., 2020). It is noteworthy that the competition between weeds and crops may be intensified if there are limited resources necessary for plant development in the production environment (COELHO et al., 2020). Given the damage caused by weeds, the need to control these species to ensure the yield potential of maize becomes evident, with the chemical method with herbicides being the main strategy.

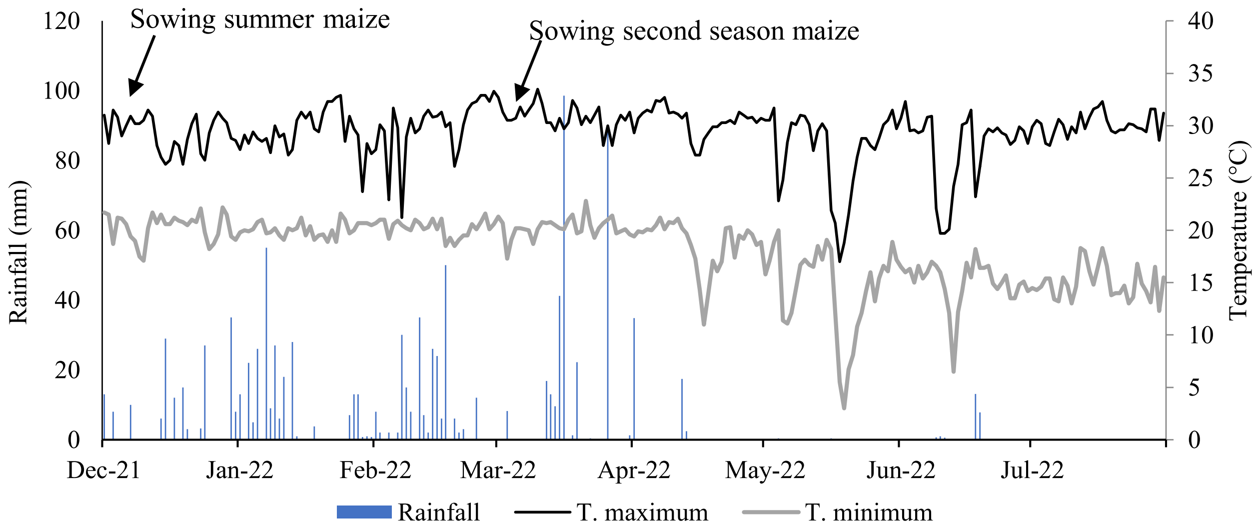
The use of herbicides ensures good selectivity of active ingredients registered for the crop (MAIA et al., 2019). However, there are external factors that can alter the crop's tolerance to herbicides, causing damage to plant development. Soil and climate conditions, genetics of new hybrids, the stage of the plants at the time of application and the dose are some of the factors that may alter the selectivity of a given herbicide for maize. It is essential to continually carry out studies to evaluate the selectivity of herbicides for maize, since there are always new hybrids being released, which may show differential sensitivity to the active ingredients used in the management of weeds in this crop (CAVALIERI et al., 2008).

Maize cultivation has been undergoing technological changes in recent times with the adoption of genetically modified (GMO) hybrids by farmers. This was aimed at resistance to herbicides, which until then were non-selective and also with the insertion of *Bt* proteins. Data from 2017/2018 season showed that 65.4% of maize hybrids available on the Brazilian market were GMO and 34.6% were conventional (non-GMO) (PEREIRA FILHO; BORGHI, 2018). However, for *Bt* technology to be sustainable, it is fundamental to establish refuge areas with conventional hybrids of similar size and vegetative cycle (RESENDE et al., 2014). Furthermore, some farmers cultivate conventional maize hybrids aimed at niche markets, obtaining differentiated remuneration from the sale of these grains. This situation highlights the need for research aimed at elucidating the selectivity of herbicides involving new maize hybrids.

Given this context, the objective was to evaluate the selectivity of herbicides applied in pre- and post-emergence of a conventional maize hybrid cultivated in the *Cerrado* biome of Brazil.

MATERIALS AND METHODS

The experiments were set up in the field located in the municipality of Rio Verde (17º47'01"S; 51º00'14"W; 787 m), Goiás State, Brazil. The first experiment was conducted from 12/19/2021 to 04/27/2022, corresponding to summer maize cultivation, while the second experiment was conducted from 02/11/2022 to 07/14/2022, consisting of the evaluation of second crop cultivation. According to Köppen's classification, the climate in the municipality of Rio Verde is type Aw, which is called "tropical with dry season", characterized by having more intense rainfall in summer compared to winter. During the time which the experiments were carried out, the climate data related to rainfall and maximum and minimum air temperature were recorded (Figure 1).



Source: Instituto Nacional de Meteorologia – INMET (2024). Rio Verde, GO, Brazil

Figure 1. Rainfall (mm) and maximum and minimum air temperature (°C) during the time in which experiments were carried out with herbicides applied pre- and post-emergence in maize crop.

Before setting up the experiments, soil samples were analyzed at a depth of 0.0 to 0.2 m. The results of the analysis of the physicochemical properties of the experiment conducted with summer maize were: pH in $CaCl_2$ of 5.0; 4.3 $cmol_c$ dm^{-3} of H^+ + Al^{+3}; 1.7 $cmol_c$ dm^{-3} of Ca^{+2}; 0.5 $cmol_c$ dm^{-3} of Mg^{+2}; 0.19 $cmol_c$ dm^{-3} of K^+; 43.0 mg dm^{-3} of P; 24.0 g dm^{-3} O.M.; 37.8% sand; 18.2% silt and 44.0% clay (clay texture). For the experiment conducted with second season maize, the following results were obtained from soil analysis: pH in $CaCl_2$ of 5.1; 2.3 $cmol_c$ dm^{-3} of H^+ + Al^{+3}; 1.5

$cmol_c\ dm^{-3}$ of Ca^{+2}; 0.9 $cmol_c\ dm^{-3}$ of Mg^{+2}; 0.13 $cmol_c\ dm^{-3}$ of K^{+}; 38.7 mg dm^{-3} of P; 18.6 g dm^{-3} of O.M.; 40.1% sand; 12.0% silt, and 47.9% clay (clay texture).

Prior to offsetting up the experiments, the weed community present in the experimental areas was desiccated through sequential applications of a glyphosate-based product. Maize sowing was carried out mechanically on 12/19/2021 and 02/11/2022, for summer and second season maize, respectively, adopting a row spacing of 0.5 m and a sowing depth of 0.03 m. Seed density adopted was 3.5 seeds per linear meter, using the maize hybrid NK 508 (early hybrid, with stay green, and orange-yellow grains), which is characterized by not having any biotechnology insertion (non-GMO) (SYNGENTA, 2023). The seeds used in the experiment received industrial treatment with fungicides and insecticides to prevent diseases and pests, respectively, in the seedling emergence. In both experiments, fertilization at the time of sowing the crop was carried out with 250 kg ha^{-1} of 09-25-25 (N-P_2O_5-K_2O). The emergence of seedlings occurred on 12/24/2021 and 02/16/2022, respectively. Furthermore, 30 days after crop emergence, nitrogen fertilization was carried out in both experiments, with the application of 80 kg ha^{-1} of urea.

In both experiments, during maize development, actions were carried out to control pests and diseases in order to try to preserve the yield potential of the crop. All insecticide and fungicide applications were carried out using a trailed sprayer, adopting a spray volume equivalent to 150 L ha^{-1}. Furthermore, all experimental units were weeded throughout the maize development cycle, with the aim of eliminating the effect of weed interference on the crop, leaving the plants exposed only to the effects of the herbicide treatments.

For each experiment, the design used was randomized completely blocks, evaluating twelve treatments and four replications. The treatments were composed of herbicides applied in different application modalities, with selection of only active ingredients that are registered for maize in Brazil (Table 1). The experimental units were composed of seven 5-m-long sowing rows, spaced 0.5 m apart (total area of 17.5 m^2). Only the five central rows of the experimental unit were considered as the usable area for the evaluations, excluding 0.5 m from each end (usable area of 10.0 m^2).

Table 1. Treatments (pre- and post-emergence herbicides and respective doses) evaluated in selectivity experiments against conventional maize.

Treatments	Dose (g a.i. ha^{-1})	Modality (Stage)[2/]	Commercial products (Manufacturer)
S-metolachlor	1,440	PRE	Dual Gold (Syngenta)
S-metolachlor	1,680	PRE	Dual Gold (Syngenta)
Mesotrione + atrazine[1/]	115.2 + 2,000	POST (V4)	Callisto (Syngenta) + Proof (Syngenta)
Mesotrione + atrazine[1/]	192 + 2,000	POST (V4)	Callisto (Syngenta) + Proof (Syngenta)
Tembotrione + atrazine[1/]	75.6 + 2,000	POST (V4)	Soberan (Bayer) + Proof (Syngenta)
Tembotrione + atrazine[1/]	100.8 + 2,000	POST (V4)	Soberan (Bayer) + Proof (Syngenta)
Nicosulfuron + atrazine[1/]	16 + 2,000	POST (V4)	Sanson (ISK) + Proof (Syngenta)
Nicosulfuron + atrazine[1/]	24 + 2,000	POST (V4)	Sanson (ISK) + Proof (Syngenta)
[Mesotrione + atrazine][1/]	120 + 1,200	POST (V4)	Calaris (Syngenta)
2 x [Mesotrione + atrazine][1/]	60 + 600	POST (V2 / V4)	2 x Calaris (Syngenta)
Atrazine[1/]	2,000	POST (V4)	Proof (Syngenta)
Weeded control	-	-	-

[1/] Added Assist® at a dose of 0.5% V/V. [2/] PRE: Application carried out in pre-emergence of maize, immediately after crop sowing; POST: Application carried out in post-emergence of maize plants. "[]": Active ingredients in brackets indicate commercially formulated mixtures. "2 x": Indicates sequential application.

The pre-emergence application (sowing and application modality) of the herbicides was carried out on 12/19/2021 and 02/11/2022 for the summer and second season maize experiments, respectively. The first post-emergence application, called Application A, was carried out on 01/18/2022 and 03/07/2022 for the experiments conducted in the summer and second season, respectively. At the time of this application, the maize plants were in the V2 phenological stage (2 fully expanded leaves), with a height varying from 0.15 to 0.20 m. The second post-emergence application (Application B) was carried out on 02/01/2022 and 03/15/2022 for the experiments with summer and second season maize, respectively. At the time of Application B, the maize plants were at the V4 phenological stage (4 fully expanded leaves), with a height ranging from 0.30 to 0.40 m.

In all applications (pre- and post-emergence), a CO_2-based constant pressure knapsack sprayer was used, equipped with a bar with six fan-type nozzles XR-110.02, application range of 3 m, under pressure of 2.0 kgf cm^{-2}. These application conditions provided the equivalent of 200 L ha^{-1} of spray solution. It should be noted that at the time of the six applications (three in each experiment), the soil was moist, the air temperature varied between 23.0 and 28.0 °C, the relative humidity remained above 62.0% and the wind speed fluctuated between 1.5 and 3.2 km h^{-1}.

The variables evaluated were phytointoxication, stand, plant height, percentage of lodging, 100-grain mass and yield of maize. For phytointoxication assessments, the plants present in the weeded control were used as reference. The percentage of intoxication of maize plants was evaluated at 7 and 14 days after emergence (DAE) and at 7, 14 and 28 days after Application B (DAA-B). The phytointoxication of the crop was evaluated using a visual scale, 0-100%, where 0% means no symptoms and 100% death of all plants (SBCPD, 1995).

At the time of maize harvest, stand, plant lodging percentage and plant height assessments were carried out. When evaluating the crop stand, the number of plants present in 4 linear meters of the usable area of each experimental unit was counted, with the results expressed in plants per linear meter. The percentage of lodging was obtained by counting plants that showed deviations in relation to the architectural pattern expected for maize, being considered atypical plants that were completely bedded (prostrate) and also those that formed an angle of less than 90º in relation to the ground surface. This count of fallen/bedded plants was also carried out in 4 linear m of the usable area of each experimental unit, with the values presented as a percentage. To evaluate plant height, the distance from the ground level to the height of the maize tassel was measured, sampling five plants per experimental unit.

In addition to the aforementioned evaluations, at the time of maize harvesting, 100-grain mass and crop yield were also measured. The assessment of 100-grain mass was carried out by counting 100 grains, which were subsequently weighed on a precision scale and had their moisture corrected to 13.0%. To determine yield, all ears present in the usable area of each experimental unit were manually harvested (27/04/2022 and 14/07/2022, summer and second season, respectively), subsequently threshed, packaged, identified and weighed, and the moisture content of the grains was corrected to 13.0% in all treatments.

Data analysis from the two experiments was carried out using the SISVAR software (FERREIRA, 2019). For statistical analysis, the data were subjected to analysis of variance using the F test ($p \geq 0.05$) and when a significant effect was found, the means were grouped using the Scott-Knott test ($p \geq 0.05$).

RESULTS AND DISCUSSION

Experiment conducted with maize grown in summer season

For the initial measurement of the selectivity of an herbicide, one of the most important variables to be measured in studies conducted for this purpose is phytointoxication, as this allows the rapid visualization of injuries to plants arising from the toxic effect of the molecule (BRAZ et al., 2016). At 7 DAE, symptoms of injury were observed in maize plants only in the treatments that received pre-emergence herbicide application (S-metolachlor) (Table 2). On this occasion, the increase in the applied dose of S-metolachlor led to an increase in the percentage of injuries observed in maize plants. Despite the visualization of injuries arising from the application of S-metolachlor in pre-emergence, the percentages of phytointoxication obtained in this work are classified as low intensity and the symptoms observed were related to a slight reduction in the size of the plants (data not shown).

In the phytointoxication assessment carried out at 14 DAE, again, the same behavior was observed in which the increase in the dose of S-metolachlor applied pre-emergence led to increases in the intensity of injuries seen on maize plants. In this evaluation, the application of S-metolachlor, at doses of 1,440 and 1,680 g a.i. ha^{-1}, led to intoxication percentages of 13.8 and 17.5%, respectively (Table 2). S-metolachlor is registered for maize crop in pre-emergence applications aimed at controlling grasses and some broadleaf (with small seeds) weeds (PROCÓPIO et al., 2001). Despite the selectivity that the active ingredient S-metolachlor traditionally has for the crop, it has already been reported in the literature that increasing the applied dose of this herbicide can cause a reduction in shoot biomass and that the size of the maize seed can influence the initial tolerance of the crop in soils with previous application of S-metolachlor (ROSENTHAL et al., 2006).

In the third phytointoxication assessment (7 DAA-B), symptoms resulting from applications in post-emergence of conventional maize plants were already seen (Table 2). Despite this, treatments that received pre-emergence application of S-metolachlor, regardless of the dose evaluated, persisted with the highest percentages of intoxication to maize plants. Furthermore, following the treatments mentioned above, the associations based on atrazine and herbicides with a control spectrum on grasses, mesotrione (higher dose), tembotrione and nicosulfuron (both doses) consisted of the second group of treatments that caused higher percentages of injuries to maize, with values varying between 3.8 and 7.0%. On this occasion, no symptoms of injury were observed on maize plants resulting from the post-emergence application of atrazine alone (2,000 g a.i. ha^{-1}).

At 14 and 28 DAA-B, the results of the phytointoxication assessments were similar to those observed previously, since the highest percentage levels were seen in treatments with pre-emergence herbicide application (Table 2). Despite this, on these occasions the intoxication percentages observed were of low intensity (≤ 12.5%). In all treatments, the percentage of phytointoxication were lower in the last time of evaluation. Thus, it is possible notice the capacity to recover from injuries caused by application of herbicides in conventional hybrid NK 508, indicating the good selectivity for the conditions under which the experiment was conducted. In relation to the crop stand, no differences were observed in the population density depending on the application of herbicides in pre- and post-emergence of the maize grown in summer season (Table 3). These results corroborate those observed in the phytotoxicity assessments, since the injury scores were classified as low intensity, indicating a reduced risk of plant mortality due to the toxic action of the herbicides evaluated. The general average maize stand, considering all treatments evaluated in the experiment, remained at a density of 3.15 plants m^{-1}, which totals an estimated population of 63,000 plants ha^{-1}.

Table 2. Average percentage values of phytointoxication caused by herbicides applied pre- and post-emergence in conventional maize hybrid.

Treatments	Dose (g a.i. ha^{-1})	Phytointoxication (%)				
		7 DAE	14 DAE	7 DAA-B	14 DAA-B	28 DAA-B
		Summer season				
S-metolachlor	1,440	7.5 b (± 2.9)	13.8 b (± 2.5)	13.8 c (± 4.8)	11.3 c (± 2.5)	9.5 b (± 1.0)
S-metolachlor	1,680	11.3 c (± 2.5)	17.5 c (± 2.9)	18.8 c (± 2.5)	12.5 c (± 2.9)	10.0 b (± 0.0)
Mesotrione + atrazine	115.2 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	0.8 a (± 1.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Mesotrione + atrazine	192 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	5.0 b (± 0.0)	2.5 b (± 2.9)	0.0 a (± 0.0)
Tembotrione + atrazine	75.6 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	4.0 b (± 3.4)	3.3 b (± 2.4)	0.0 a (± 0.0)
Tembotrione + atrazine	100.8 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	5.0 b (± 4.1)	3.8 b (± 2.5)	2.5 a (± 2.9)
Nicosulfuron + atrazine	16 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	7.0 b (± 4.8)	6.0 b (± 2.4)	0.0 a (± 0.0)
Nicosulfuron + atrazine	24 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	7.0 b (± 2.4)	4.5 b (± 1.0)	1.3 a (± 2.5)
[Mesotrione + atrazine]	120 + 1,200	0.0 a (± 0.0)	0.0 a (± 0.0)	3.8 b (± 2.5)	1.3 b (± 2.5)	0.0 a (± 0.0)
2x [Mesotrione + atrazine]	60 + 600	0.0 a (± 0.0)	0.0 a (± 0.0)	1.3 a (± 2.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Atrazine	2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)
Weeded control	-	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)
$F_{Calculated}$		43.6*	117.4*	14.9*	17.4*	40.5*
CV (%)		72.4	43.4	53.3	54.8	60.5
		Second season				
S-metolachlor	1,440	16.3 b (± 2.5)	17.5 b (± 2.9)	17.5 b (± 2.9)	18.3 b (± 2.4)	11.0 b (± 1.2)
S-metolachlor	1,680	18.3 b (± 2.4)	22.5 c (± 2.9)	20.0 b (± 1.6)	17.0 b (± 2.4)	11.8 b (± 2.4)
Mesotrione + atrazine	115.2 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	0.8 a (± 1.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Mesotrione + atrazine	192 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	1.3 a (± 2.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Tembotrione + atrazine	75.6 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	2.0 a (± 2.4)	0.0 a (± 0.0)	0.0 a (± 0.0)
Tembotrione + atrazine	100.8 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	2.5 a (± 5.0)	0.0 a (± 0.0)	0.0 a (± 0.0)
Nicosulfuron + atrazine	16 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	0.8 a (± 1.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Nicosulfuron + atrazine	24 + 2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	4.0 a (± 2.7)	0.0 a (± 0.0)	0.0 a (± 0.0)
[Mesotrione + atrazine]	120 + 1,200	0.0 a (± 0.0)	0.0 a (± 0.0)	2.5 a (± 2.9)	0.0 a (± 0.0)	0.0 a (± 0.0)
2x [Mesotrione + atrazine]	60 + 600	0.0 a (± 0.0)	0.0 a (± 0.0)	1.3 a (± 2.5)	0.0 a (± 0.0)	0.0 a (± 0.0)
Atrazine	2,000	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)
Weeded control	-	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)	0.0 a (± 0.0)
$F_{Calculated}$		192.2*	177.9*	32.5*	199.5*	132.7*
CV (%)		33.8	35.4	54.8	33.1	40.6

* Significant by F test ($p \geq 0.05$). Means followed by different letters in the columns differ from each other using the Scott-Knott test ($p \geq 0.05$).

In the experiment conducted in the summer season, lodging of maize plants was observed in all treatments (Table 3). Despite this, no induction of a specific herbicide molecule or the association of two active ingredients with the tipping over/lodging of maize plants was observed, as no significant effect was seen for this variable among treatments. In the literature, there are several reports of factors affecting the tipping over/lodging of maize plants, which may be related to the genetics of the hybrid (SHAO et al., 2021; ZHANG et al., 2021).

For the evaluation of the final height of maize plants, the only treatment to cause reduction in the values of this response variable compared to the others was the one composed of the sequential application of the formulated mixture with [mesotrione + atrazine], using in both applications the dose of [60 + 600] g a.i. ha^{-1} (Table 3). Despite this reduction in the final height of maize plants that developed under the effect of this treatment compared to the others, the percentage of reduction observed was low, not having a significant impact on other crop yield parameters. Mitchell et al. (2001) reported that the herbicide mesotrione is safe for use in maize crop, within the range of recommended doses, promoting very low levels of injury and not affecting grain yield.

Table 3. Average values of plant stand, percentage of lodging, and plant height of conventional maize after the application of herbicides in pre- and post-emergence of the crop.

Treatments	Dose (g a.i. ha^{-1})	Stand (plants m^{-1})	Plant lodging (%)	Height (cm)
		Summer season		
S-metolachlor	1,440	3.20 a (± 0.73)	14.3 a (± 7.9)	220.8 a (± 4.3)
S-metolachlor	1,680	3.13 a (± 0.53)	38.6 a (± 43.8)	214.8 a (± 4.1)
Mesotrione + atrazine	115.2 + 2,000	2.83 a (± 0.25)	23.9 a (± 27.6)	220.0 a (± 4.2)
Mesotrione + atrazine	192 + 2,000	3.13 a (± 0.53)	38.5 a (± 31.0)	217.5 a (± 5.6)
Tembotrione + atrazine	75.6 + 2,000	3.13 a (± 0.33)	46.0 a (± 41.2)	219.0 a (± 4.2)
Tembotrione + atrazine	100.8 + 2,000	2.70 a (± 0.53)	24.6 a (± 28.6)	219.0 a (± 5.0)
Nicosulfuron + atrazine	16 + 2,000	3.25 a (± 0.30)	28.9 a (± 33.3)	213.3 a (± 5.4)
Nicosulfuron + atrazine	24 + 2,000	3.20 a (± 0.55)	29.8 a (± 27.8)	217.0 a (± 3.2)
[Mesotrione + atrazine]	120 + 1,200	2.95 a (± 0.55)	49.2 a (± 33.3)	215.8 a (± 5.4)
2x [Mesotrione + atrazine]	60 + 600	3.45 a (± 0.53)	25.2 a (± 19.0)	209.0 b (± 5.0)
Atrazine	2,000	3.13 a (± 0.83)	36.0 a (± 27.4)	211.5 a (± 6.2)
Weeded control	-	3.33 a (± 0.13)	39.0 a (± 23.6)	218.8 a (± 3.8)
$F_{Calculated}$		0.62^{ns}	1.1^{ns}	2.5*
CV (%)		17.0	59.5	2.1
		Second season		
S-metolachlor	1,440	3.25 a (± 0.20)	0.0 (± 0.0)	204.5 a (± 3.3)
S-metolachlor	1,680	2.88 a (± 0.33)	0.0 (± 0.0)	199.0 a (± 1.8)
Mesotrione + atrazine	115.2 + 2,000	3.20 a (± 0.13)	0.0 (± 0.0)	199.3 a (± 4.3)
Mesotrione + atrazine	192 + 2,000	3.33 a (± 0.25)	0.0 (± 0.0)	203.3 a (± 1.7)
Tembotrione + atrazine	75.6 + 2,000	3.25 a (± 0.45)	0.0 (± 0.0)	202.8 a (± 3.7)
Tembotrione + atrazine	100.8 + 2,000	3.20 a (± 0.33)	0.0 (± 0.0)	200.3 a (± 2.2)
Nicosulfuron + atrazine	16 + 2,000	3.08 a (± 0.13)	0.0 (± 0.0)	198.8 a (± 3.5)
Nicosulfuron + atrazine	24 + 2,000	3.38 a (± 0.43)	0.0 (± 0.0)	199.8 a (± 5.6)
[Mesotrione + atrazine]	120 + 1,200	3.20 a (± 0.25)	0.0 (± 0.0)	200.0 a (± 3.9)
2x [Mesotrione + atrazine]	60 + 600	3.33 a (± 0.13)	0.0 (± 0.0)	200.0 a (± 3.7)
Atrazine	2,000	3.20 a (± 0.43)	0.0 (± 0.0)	201.5 a (± 3.8)
Weeded control	-	3.13 a (± 0.15)	0.0 (± 0.0)	203.5 a (± 0.6)
$F_{Calculated}$		0.8^{ns}	-	1.3^{ns}
CV (%)		9.3	-	1.8

^{ns} Not significant by F test (*p≥0.05*). Means followed by different letters in the columns differ from each other using the Scott-Knott test (*p≥0.05*).

The 100-grain mass and yield of conventional maize were not influenced by the different herbicides applied pre- and post-emergence of the crop (Table 4). The average 100-grain mass and yield, considering all treatments evaluated, were 30.3 g and 8,176 kg ha^{-1}, respectively. As it was maize grown under summer season conditions, it was expected to obtain an average yield higher than that observed in the experiment. Despite this, some factors ended up contributing to this final yield result obtained, especially the occurrence of a period of drought in the final grain filling phase of the crop (Figure 1), as well as the high incidence of maize leafhoppers (*Dalbulus maidis*), an insect that acts as a vector of the maize stunt complex (OLIVEIRA et al., 2007). Even with successive applications of insecticides, pest pressure during this sowing season was high, as observed on other farms of the region.

As final considerations regarding the experiment conducted in the summer season, the selectivity that the herbicides applied in pre- and post-emergence had for the conventional maize hybrid NK508 can be highlighted, since these treatments did not cause high percentages of injuries to the plants and did not affect the stand, final height, grain mass and yield. These results corroborate those obtained by Giraldeli et al. (2019), who found that the herbicides atrazine, mesotrione, nicosulfuron and tembotrione, applied alone or in mixtures, were selective to a conventional maize hybrid (P30F53) in post-emergence application performed at V4 phenological stage. Furthermore, although a high percentage of fallen plants was observed, a cause and effect relationship was not established regarding the use of the herbicides evaluated in the present experiment. In this context, future studies are necessary to elucidate which agronomic factors have contributed to the tipping over/lodging of plants in the hybrid NK508, since it has high yield potential and good adaptability, behaving as an important genotype for farmers who aim for conventional maize cultivation.

Table 4. Average values of 100-grain mass and yield of conventional maize after application of herbicides in pre- and post-emergence of the crop.

Treatments	Dose (g a.i. ha^{-1})	100-grain mass (g)	Yield (kg ha^{-1})
		Summer season	
S-metolachlor	1,440	31.3 a (± 2.2)	8,432 a (± 981.2)
S-metolachlor	1,680	30.2 a (± 1.6)	8,476 a (± 307.9)
Mesotrione + atrazine	115.2 + 2,000	31.1 a (± 1.7)	8,221 a (± 521.5)
Mesotrione + atrazine	192 + 2,000	29.3 a (± 1.1)	8,330 a (± 522.5)
Tembotrione + atrazine	75.6 + 2,000	28.1 a (± 2.4)	8,145 a (± 513.6)
Tembotrione + atrazine	100.8 + 2,000	31.1 a (± 1.6)	8,758 a (± 1,049.7)
Nicosulfuron + atrazine	16 + 2,000	29.5 a (± 2.5)	7,902 a (± 726.7)
Nicosulfuron + atrazine	24 + 2,000	30.1 a (± 1.6)	8,073 a (± 1,061.8)
[Mesotrione + atrazine]	120 + 1,200	29.6 a (± 1.7)	7,788 a (± 494.6)
2x [Mesotrione + atrazine]	60 + 600	29.6 a (± 1.5)	7,816 a (± 276.7)
Atrazine	2,000	32.3 a (± 8.8)	7,841 a (± 668.4)
Weeded control	-	31.7 a (± 3.6)	8,320 a (± 677.6)
$F_{Calculated}$		0.8^{ns}	0.8^{ns}
CV (%)		10.7	8.2
		Second season	
S-metolachlor	1,440	25.5 a (± 2.3)	7,599 a (± 887.3)
S-metolachlor	1,680	23.7 a (± 1.7)	7,300 a (± 440.4)
Mesotrione + atrazine	115.2 + 2,000	23.8 a (± 1.1)	7,344 a (± 600.8)
Mesotrione + atrazine	192 + 2,000	24.1 a (± 1.5)	7,340 a (± 111.2)
Tembotrione + atrazine	75.6 + 2,000	24.6 a (± 0.8)	7,611 a (± 413.2)
Tembotrione + atrazine	100.8 + 2,000	24.2 a (± 1.5)	7,334 a (± 503.2)
Nicosulfuron + atrazine	16 + 2,000	24.4 a (± 0.8)	6,966 a (± 287.0)
Nicosulfuron + atrazine	24 + 2,000	24.2 a (± 0.6)	7,071 a (± 852.3)
[Mesotrione + atrazine]	120 + 1,200	24.2 a (± 1.6)	7,260 a (± 346.2)
2x [Mesotrione + atrazine]	60 + 600	23.9 a (± 0.8)	7,462 a (± 714.4)
Atrazine	2,000	24.8 a (± 0.9)	7,638 a (± 742.3)
Weeded control	-	24.2 a (± 1.3)	7,495 a (± 876.7)
$F_{Calculated}$		0.8^{ns}	0.5^{ns}
CV (%)		5.1	7.8

^{ns} Not significant by F test ($p \geq 0.05$). Means followed by different letters in the columns differ from each other using the Scott-Knott test ($p \geq 0.05$).

Experiment conducted with maize grown in second season

At 7 DAE, percentages of intoxication of maize plants varying between 16.3 and 18.3% were observed, with no differences seen in the intensity of symptoms due to the dose of S-metolachlor used (Table 2). In contrast, in the second evaluation (14 DAE), the application of S-metolachlor at the highest dose (1,680 g a.i. ha^{-1}) promoted an increase in the percentages of injuries observed in maize plants compared to the lowest dose (1,440 g a.i. ha^{-1}). It is worth noting that comparing the injury symptoms observed in the experiment conducted in the summer season with those observed in the second season, a greater intensity of injuries was seen in the second sowing season of conventional maize. In contrast, Janak and Grichar (2016), when evaluating the selectivity of S-metolachlor (1,329 g a.i. ha^{-1}) applied pre-emergence of the maize crop, did not verify symptoms of phytointoxication and observed grain yield statistically similar to that of the weeded control.

From the evaluation carried out at 7 DAA-B, in addition to the effect of herbicides applied pre-emergence, the phytotoxicity scores were already influenced by the treatments applied post-emergence of maize. On this occasion, maize plants that developed in treatments with application of S-metolachlor in pre-emergence still showed moderate percentages of injuries (17.5 to 20.0%), with no effect of the applied dose on the intensity of symptoms (Table 2). In relation to maize phytointoxication resulting from the application of post-emergence herbicides, the percentage levels were low in all treatments, with no differences being found in the intensity of symptoms observed in maize plants among the herbicides evaluated.

In the evaluations carried out at 14 and 28 DAA-B, symptoms of intoxication were only observed in maize plants that received pre-emergence application of S-metolachlor, with no differences between the applied doses of this herbicide (Table 2). Thus, none of the treatments applied post-emergence caused symptoms of intoxication after 14 DAA-B, demonstrating the good capacity that the NK 508 hybrid has in recovering from injuries resulting from the use of herbicides.

In a similar way to what was seen for the summer season, in the experiment carried out in second season, no differences were observed in the density of maize plants as a result of the application of herbicide treatments (Table 3). In this specific experiment, plant density, considering the average observed in all treatments, was 3.2 plants m^{-1}, which represents an estimated population of 64,000 plants ha^{-1}. Regarding the evaluation of plant height, no effect of treatments was observed impacting this variable (Table 3).

Unlike what was observed in the experiment conducted in the summer season, in the experiment carried out under second season conditions, no tipping over/lodging of maize plants was observed in any of the treatments (Table 3). The volume of precipitation that the maize plants were exposed to in each experiment was different, with a smaller amount of water available in the experiment conducted in the second season (Figure 1). In these situations, the plants may have directed part of the assimilates to the growth of the root system in subsurface in search of the water gradient, making them more tolerant to tipping over/lodging.

Furthermore, regarding the chemical composition of the soil in the experimental areas, the fact that the experiment conducted in the summer was in an environment with higher values of $H^+ + Al^{+3}$ may have contributed to restrictions in the development of the maize root system, making the plants more susceptible to tipping over and lodging processes. Another point that should be highlighted refers to the fact that a high population density of maize leafhoppers was seen in the experiment conducted during the summer season, which may have contributed to the greater occurrence of plant tipping over (CUNHA et al., 2023). Finally, maize plants in the experiment conducted in the second season had, in general, a lower final height compared to those in the experiment carried out in the summer season, which may also have contributed to reducing plant lodging.

Similar to what was observed in the experiment carried out in the summer season, differences in 100-grain mass and yield were not seen due to the application of different herbicide treatments (Table 4). For the experiment carried out under second season conditions, the average values among treatments for 100-grain mass and yield were 24.3 g and 7,369 kg ha^{-1}, respectively. Cabral et al. (2023), in work carried out with maize grown under second season conditions, also observed that all herbicide treatments were also selective for the crop. These results, no statistical difference among the averages, attest to the selectivity that the evaluated treatments have for the conventional maize hybrid NK508, accrediting these herbicides to be used in the weed management of this crop.

When considering the market demand for maize grains from hybrids that are not genetically modified, with regard to weed management practices, an impression is created that restrictions in the chemical control of the weed community can be seen due to the lack of possibility of using herbicides such as glyphosate and glufosinate. Furthermore, considering the herbicides that can be used to control weeds in conventional maize hybrids, there is a fear that losses resulting from plant intoxication will be observed (CORREIA; LENZA, 2024). In this context, the present work demonstrates that even in conventional maize hybrids, there are alternative selective herbicides, which have different modes of action and can be applied both pre- and post-emergence. The scenario described demonstrates that the use of conventional maize hybrid will enable the rotation of mechanisms and modalities, contributing to a reduction in selection pressure on weeds for the resistance process.

CONCLUSIONS

Regardless of when the experiment was conducted, herbicides applied pre- and post-emergence of maize cause low percentages of phytointoxication. The increase in the dose of S-metolachlor applied pre-emergence increases the percentage of injuries to maize plants, without, however, impacting other parameters of crop development.

In both experiments, none of the treatments caused reductions in the crop stand, confirming the absence of plant mortality due to the application of herbicides in pre- and post-emergence. Plant lodging was only seen in the experiment conducted with summer maize, with no effect observed among treatments for this response variable.

100-grain mass and yield are not altered as a result of the application of herbicides in pre- and post-emergence of the crop. All herbicides evaluated show selectivity for the conventional maize hybrid.

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