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Article

# CONTROL OF ALS- AND EPSPS-RESISTANT *Amaranthus palmeri* BY ALTERNATIVE HERBICIDES APPLIED IN PRE- AND POST-EMERGENCE

*Controle de **Amaranthus palmeri** Resistente a Inibidores da ALS e EPSPS por Herbicidas Alternativos Aplicados em Pré e Pós-Emergência*

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ABSTRACT - The emergence of resistant biotypes of the *Amaranthus palmeri* species in cotton production areas of the state of Mato Grosso, Brazil, generated the need for correct identification of this species and information on viable herbicidal tools for their management. Thus, greenhouse experiments were conducted to evaluate the efficacy of alternative herbicides applied to *A. palmeri* in pre and post emergence. A randomized block design with four replications was used. The efficacy of herbicides applied in pre emergence was evaluate in two experiments, one in a clayey and other in a sandy soil; 9 herbicide treatments (8 with herbicide application and a control without application) were applied on each soil. Subsequently, two experiments with different populations of *A. palmeri* were conducted, using a 13 x 2 factorial arrangement, to evaluate the efficacy of herbicides applied in post emergence. The factors consisted of 13 herbicide treatments (12 with herbicide application and a control without application) and two weed development stages (2-4 and 6-8 leaves). Pre-emergence application of the flumioxazin, S-metolachlor, isoxaflutole, and trifluralin herbicides controlled the weed satisfactorily in both evaluated soils. The sulfentrazone and metribuzin herbicides were effective in the sandy soil, and diuron was effective in the clayey soil. The clomazone herbicide did not successfully controlled the *A. palmeri* plants in any of the soils. All post-emergence herbicide treatments were effective for the management of *A. palmeri* plants, when they were applied at the 2-4 leaf stage.

**Keywords:** caruru, weed control, resistance, phenology, soil texture.

*RESUMO - Devido à introdução do biótipo resistente da planta daninha caruru-palmeri (**Amaranthus palmeri**) nas áreas de produção de algodão do Estado do Mato Grosso, tornou-se muito importante a correta identificação dessa espécie, bem como o conhecimento de ferramentas herbicidas viáveis para seu manejo. Assim, foram desenvolvidos experimentos em casa de vegetação com o objetivo de avaliar a eficácia de herbicidas alternativos aplicados em pré e pós-emergência sobre o caruru-palmeri. Os experimentos foram realizados em delineamento de blocos casualizados com quatro repetições. Primeiramente, realizaram-se dois experimentos para avaliar a eficácia de herbicidas aplicados em pré-emergência (solo arenoso e argiloso). Para isso, foram utilizados nove tratamentos herbicidas (oito herbicidas + testemunha sem aplicação) em cada textura de solo. Posteriormente, realizaram-se dois experimentos em esquema fatorial 13 x 2 para avaliar a eficácia de herbicidas aplicados em pós-emergência, um para cada população de **A. palmeri**. O primeiro fator correspondeu aos herbicidas (12 herbicidas + testemunha sem aplicação), e o segundo, a dois estádios de*

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*desenvolvimento da planta daninha (2-4 folhas e 6-8 folhas). Em pré-emergência, os herbicidas flumioxazina, S-metolachlor, isoxaflutole e trifluralina controlaram a planta daninha de forma satisfatória nos dois solos estudados. Sulfentrazone e metribuzin foram eficazes somente em solo arenoso, enquanto o diuron foi eficaz em solo argiloso. O herbicida clomazone não teve sucesso no controle de caruru-palmeri em nenhum dos solos estudados. Todos os tratamentos herbicidas aplicados em pós-emergência foram ferramentas eficazes para o manejo de caruru-palmeri, desde que aplicados no estádio de duas a quatro folhas.*

**Palavras-chave:** caruru-palmeri, alternativa de controle, resistência, fenologia, textura de solo.

## INTRODUCTION

*Amaranthus palmeri* is indigenous to arid regions of the Mid-South USA and northern Mexico, and is present in several countries (Sauer, 1957). This species has become one of the main weeds in the USA due to its biological characteristics and selection of herbicide-resistant biotypes with different mechanisms of action (Legleiter and Johnson, 2013). *A. palmeri* was first found in Brazil in 2015, in cotton growing areas in the state of Mato Grosso (Carvalho et al., 2015). It is a very important weed species because of its potential negative impact on crops in this region and throughout the country.

*A. palmeri* is an opportunistic and competitive species of high fertility and germination, rapid growth, and phenotypic capacity and phenological plasticity that allow seed production under different conditions (Gonçalves Netto et al., 2018). It is a dioecious species, thus, part of the plants in a population will have only female and other part only male flowers (Küpper et al., 2017). This characteristic facilitates its identification, since most amaranth species found in Brazil have male and female flowers on the same plant, being classified as monoecious species.

*A. palmeri* seeds are produced only by female plants. However, an important aggravating factor in the reproduction of this species is the ability of female flowers to produce viable seeds even without pollination (Legleiter and Johnson, 2013). According to Ward et al. (2013), *A. palmeri* plants can produce 600 thousand to 2 million seeds, and their seeds take three to eight days to germinate.

Control of *A. palmeri* populations is even more complex due to the existence of identified biotypes with simple resistance to inhibitors of EPSPS (Group G), tubulin synthesis (K1), ALS (A), carotene synthesis (HPPD) (F2), and photosystem II (FSII) (C1) (Ward et al., 2013; Heap, 2018); and multiple resistance to two or three action mechanisms: ALS/EPSPS; ALS/EPSPS/FSII, and ALS/FSII/HPPD (Beckie and Tardif, 2012; Ward et al., 2013; Heap, 2018).

*A. palmeri* biotypes have showed resistance to ALS inhibitors in Israel (Heap, 2018), to glyphosate in Argentina (Morichetti et al., 2013), and to glyphosate and to ALS inhibitors in Brazil (Carvalho et al., 2015; Gonçalves Netto et al., 2016). The lack of control of *A. palmeri* due to poor management or presence of resistant biotypes can negatively affect the production of several crops. Yield losses can reach 91% in maize, 65% in cotton, 68% in sorghum, 79% in soybean, 68% in peanuts, and 94% in sweet potato (Ward et al., 2013).

Therefore, integrated management to control this species is essential because it is an extremely aggressive weed. The biological characteristics of this weed justify further studies on alternative strategies for its control, mainly to prevent *A. palmeri* plants to become resistant to other herbicides. Thus, the objective of the present work was to evaluate the efficacy of alternative pre and post-emergence herbicides to control two *A. palmeri* populations resistant to glyphosate and ALS inhibitor herbicides in the state of Mato Grosso (MT), Brazil.

## MATERIAL AND METHODS

The *A. palmeri* seeds used in the present study were previously evaluated by Carvalho et al. (2015) and Gonçalves Netto et al. (2016), who found that plants from these seeds are resistant to glyphosate and ALS inhibitor herbicides. The original plants that produced these seeds were sent by producers from the municipalities of Tapurah and Ipiranga do Norte, MT, who were looking for identification of the species.

All experiments were performed in a randomized block design with four replications. The efficacy of herbicides applied in pre emergence were evaluated in two experiments, one in a clayey and other in a sandy soil. Nine herbicide treatments (eight with application of herbicides plus a control without herbicide application) were applied on each soil (Table 1). The physicochemical characteristics of the studied soils are presented in Table 2.

The sample units consisted of 1 liter plastic pots filled with clayey or sandy soil, according to the experiment, in which 0.30 g of *A. palmeri* seeds were sown. The pots were kept under irrigation in a greenhouse.

Subsequently, two experiments with different populations of *A. palmeri* were conducted, using a 13 x 2 factorial arrangement, to evaluate the efficacy of herbicides applied in post emergence. The factors consisted of 13 herbicide treatments (12 with application of herbicides plus a control without herbicide application) and two weed development stages (2-4 and 6-8 leaves) (Table 3). The *A. palmeri* populations were from Tapurah and Ipiranga do Norte, MT. For experimental purposes, each population was considered as an independent experiment.

***Table 1*** - Pre-emergence herbicide treatments used for the control of *A. palmeri* plants and their respective rates (acid equivalent or active ingredient) applied

| Treatment | Rate (sandy soil) $(g\ ha^{-1})$ | Rate (clayey soil) $(g\ ha^{-1})$ |
|---|---|---|
| 01. Control | - | - |
| 02. Flumioxazin | 40.0 | 50.0 |
| 03. S-metolachlor | 960.0 | 1440.0 |
| 04. Isoxaflutole | 75.0 | 112.5 |
| 05. Trifluralin | 1125.0 | 1350.0 |
| 06. Metribuzin | 360.0 | 480.0 |
| 07. Clomazone | 900.0 | 1000.0 |
| 08. Sulfentrazone | 400.0 | 500.0 |
| 09. Diuron | 250.0 | 375.0 |

***Table 2*** - Physicochemical analysis of the soils used

| P | M.O. | pH | K | Ca | Mg | H+Al | Al | SB | CTC | V | Clay | Sand | Silt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $(mg\ dm^{-3})$ | $(g\ dm^{-3})$ | $(CaCl_2)$ | $(mmol_c\ dm^{-3})$ | | | | | | | (%) | $(g\ kg^{-1})$ | | |
| Sandy soil | | | | | | | | | | | | | |
| 15.0 | 24.0 | 5.1 | 2.5 | 28.0 | 12.0 | 40.0 | 0.4 | 42.5 | 82.5 | 52.0 | 660.0 | 150.0 | 190.0 |
| Clayey soil | | | | | | | | | | | | | |
| 3.0 | 9.0 | 4.6 | 0.5 | 12.0 | 5.0 | 36.0 | 1.0 | 38.5 | 40.0 | 44.0 | 203.0 | 779.0 | 180.0 |

***Table 3*** - Post-emergence herbicide treatments used for the control of *A. palmeri* plants and their respective rates (acid equivalent or active ingredient) applied

| Treatment | $(g\ ha^{-1})$ |
|---|---|
| 01. Control | - |
| 02. Fomesafen | 125.0 |
| 03. Fomesafen | 250.0 |
| 04. Lactofen | 84.0 |
| 05. Lactofen | 168.0 |
| 06. Flumiclorac | 40.0 |
| 07. Flumiclorac | 70.0 |
| 08. Atrazine | 1500.0 |
| 09. Mesotrione + Atrazine | 120.0 + 1500.0 |
| 10. Tembotrione + Atrazine | 75.6 + 1500.0 |
| 11. Ammonium glufosinate | 400.0 |
| 12. Paraquat | 400.0 |
| 13. Saflufenacil | 49.0 |

Addition of oil at 0.5% $v\ v^{-1}$.

*A. palmeri* seeds were distributed in 2 liter rectangular plastic trays filled with a commercial substrate (Pinus bark, peat, and vermiculite) and vermiculite (3:1; v:v).

The plants were transplanted to 1 liter pots filled with the same substrate mixture when they reached the vegetative development stage with fully expanded cotyledon leaves – stage 10, according to Hess et al. (1997), where they remained until the end of the experiment, with an average density of three plants per pot.

The herbicide applications were carried out using a $CO_2$-pressurized backpack sprayer equipped with two flat fan nozzles (XR110.02; TeeJet®, Wheaton, USA) positioned at 0.50 m from the targets, with a relative flow rate of 200 L $ha^{-1}$. The application dates, times, air temperature and relative humidity, and average wind speed during applications are shown in Table 4.

***Table 4*** - Date, time, and weather conditions of applications of herbicides for the control of *A. palmeri* plants

| Date | Time | T(1) (ºC) | RH(2) (%) | W(3) (km $h^{-1}$) | Sky | Stage |
|---|---|---|---|---|---|---|
| 10/22/2015 | 09:30 - 09:50 | 27.9 | 72.8 | 5.4 a 7.1 | clear | 2 to 4 leaves |
| 10/29/2015 | 09:20 - 09:50 | 28.9 | 75.6 | 4.7 a 6.8 | clear | 6 to 8 leaves |
| 11/26/2015 | 08:30 – 09:20 | 28.1 | 73.7 | 4.9 a 6.5 | clear | Pre-emergence |

(1) Average air temperature; (2) Average relative humidity; (3) Average wind speed at application. Data obtained at the site, using a Thermo-Hygro-Anemometer (Kestrel 3000).

Weed control was evaluated following a percentage grade scale, in which 0% corresponded to plant with no injury and 100% corresponded to death of the plants (SBCPD, 1995). The experiment that was conducted to assess the efficacy of pre-emergence herbicides had evaluations at 30, 45, and 60 days after the application (DAA) of the treatments; and the experiment that was conducted to assess the efficacy of post-emergence herbicides had an evaluation at 28 DAA. The remaining *A. palmeri* plants were cut at the end of the experiments, placed in paper bags, and taken to a forced-air circulation oven (60 °C) for 72 hours to evaluate their shoot dry weight. The shoot dry weight was corrected to percentages, considering the weight of control plants without application of herbicides as 100%.

The collected data were subjected to analysis of variance by the F test, and when the means were significant, the Scott-Knott mean grouping test was applied at a 5% probability level. The efficacy rating was determined according to the Efficiency Scale of Frans et al. (1986), which establishes 80% as the minimum control index for weed populations.

## RESULTS AND DISCUSSION

In the pre-emergence herbicide efficacy experiment, the treatments with flumioxazin, S-metolachlor, and isoxaflutole herbicides showed satisfactory control (above 80%) of the *A. palmeri* populations up to the last evaluation (60 DAA) in both clayey and sandy soils. The trifluralin and metribuzin herbicides presented increasing control percentages over the evaluations, becoming satisfactory (above 80%) at 60 DAA, when applied to the sandy soil. Trifluralin also had satisfactory control at 60 DAA in the clayey soil. The sulfentrazone herbicide was effective only when applied to the sandy soil, and the diuron herbicide was effective only in the clayey soil. The clomazone herbicide had no satisfactory control of *A. palmeri* in any of the studied soils (Tables 5 and 6).

These results were confirmed by the accumulated shoot dry weight in each treatment; *A. palmeri* plants in treatments that had satisfactory control had lower residual shoot dry weight, reaching zero in the treatments with application of S-metolachlor and isoxaflutole, in both soils. Plants in treatments that had no effective control had higher accumulated shoot dry weight – 34% for metribuzin and 23% for clomazone in the clayey soil; and 30% for diuron and 27% for clomazone in the sandy soil (Tables 5 and 6).

Sweat et al. (1998) also found controls of *A. palmeri* greater than 80% when using S-metolachlor (1,632 g $ha^{-1}$), metribuzin (480 g $ha^{-1}$), and trifluralin (810 g $ha^{-1}$) herbicides in incorporated pre-planting; and when applying sulfentrazone (350 g $ha^{-1}$) in a greenhouse experiment using soils with 48% sand, 14% clay, and 3% organic matter. This shows that these herbicides can be effective alternatives for the control of this weed species.

The treatment with diuron was effective (above 80%) up to 30 DAA in both soils; however, it was effective only in the clayey soil at 60 DAA. The herbicide persistence in clayey soils may be higher than that in sandy soils, extending its control period. Contrastingly, soils with little organic matter, as the sandy soil used in the present experiment, have low sorption capacity, favoring the herbicide loss by leaching (Inoue et al., 2015). Clomazone was not efficient to control *A. palmeri* in any of the studied soils. Similarly, Scott et al. (2002) found no control (0%) of *A. palmeri* with application of 850 g $ha^{-1}$ of clomazone in a sandy loam soil with 1.8% organic matter.

***Table 5*** - Percentages of control of *A. palmeri* plants at 30, 45, and 60 days after application (DAA) and their shoot dry weight (%) at 60 DAA of different pre-emergence herbicides in a clayey soil

| Treatment | Rate (g ha$^{-1}$) | Control (%) | | | Shoot dry weight (%) |
|---|---|---|---|---|---|
| | | 30 DAA | 45 DAA | 60 DAA | 60 DAA |
| 01. Control | - | 0.0 c | 0.0 c | 0.00 d | 100.0 f |
| 02. Flumioxazin | 50.0 | 89.0 a | 81.8 a | 89.8 a | 5.0 b |
| 03. S-Metolachlor | 1440.0 | 87.6 a | 85.8 a | 87.0 a | 0.0 a |
| 04. Isoxaflutole | 112.5 | 96.6 a | 96.4 a | 92.0 a | 0.0 a |
| 05. Trifluralin | 1350.0 | 54.0 b | 63.0 a | 80.0 a | 12.0 c |
| 06. Metribuzin | 480.0 | 55.0 b | 39.0 b | 41.0 c | 34.0 e |
| 07. Clomazone | 1000.0 | 63.0 b | 43.0 b | 62.0 b | 23.0 d |
| 08. Sulfentrazone | 500.0 | 76.0 a | 43.0 b | 69.0 b | 22.0 d |
| 09. Diuron | 375.0 | 94.0 a | 74.0 a | 81.0 a | 14.0 c |
| | | $F_{treatment}$: 37.5* | $F_{treatment.}$: 13.4* | $F_{treatment.}$: 35.5* | $F_{treatment.}$: 754.1* |
| | | CV (%): 16.2 | CV (%): 31.1 | CV (%): 17.0 | CV (%): 8.3 |

* Significant by the F test at 5% probability; Means followed by the same letter do not differ by the Scott-Knott test at 5% probability. CV = Coefficient of variation.

***Table 6*** - Percentages of control of *A. palmeri* plants at 30, 45, and 60 days after application (DAA) and their shoot dry weight (%) at 60 DAA of different pre-emergence herbicides in a sandy soil

| Treatment | Rate (g ha$^{-1}$) | Control (%) | | | Shoot dry weight (%) |
|---|---|---|---|---|---|
| | | 30 DAA | 45 DAA | 60 DAA | 60 DAA |
| 01. Control | - | 0.0 d | 0.0 d | 0.0 c | 100.0 e |
| 02. Flumioxazin | 40.0 | 96.8 a | 93.8 a | 86.0 a | 6.0 b |
| 03. S-Metolachlor | 960.0 | 95.4 a | 97.8 a | 94.8 a | 0.0 a |
| 04. Isoxaflutole | 75.0 | 98.4 a | 99.4 a | 93.8 a | 0.0 a |
| 05. Trifluralin | 1125.0 | 76.0 b | 78.0 b | 82.0 a | 11.0 b |
| 06. Metribuzin | 360.0 | 62.0 b | 66.0 b | 87.0 a | 7.0 b |
| 07. Clomazone | 900.0 | 79.8 b | 60.0 c | 57.0 b | 27.0 c |
| 08. Sulfentrazone | 400.0 | 88.8 a | 82.0 b | 83.0 a | 9.0 b |
| 09. Diuron | 250.0 | 81.0 b | 51.0 c | 54.0 b | 30.0 d |
| | | $F_{treatment.}$: 62.7* | $F_{treatment.}$: 22.8* | $F_{treatment.}$: 52.7* | $F_{treatment.}$: 238.8* |
| | | CV (%): 13.5 | CV (%): 27.2 | CV (%): 12.9 | CV (%): 19.9 |

* Significant by the F test at 5% probability; Means followed by the same letter do not differ by the Scott-Knott test at 5% probability. CV = Coefficient of variation.

The use of protoporphyrinogen oxidase (PROTOX) inhibitor herbicides, such as flumioxazin, has increased in cotton crops of Georgia due to the emergence of resistant *A. palmeri* biotypes (Sosnoskie and Culpepper, 2014). Flumioxazin and fomesafen are the most effective residual herbicides for controlling resistant *A. palmeri* to glyphosate and ALS inhibitor herbicides (Whitaker et al., 2011). However, the overuse of these products is concerning because there are already *A. palmeri* biotypes that are resistant to fomesafen, lactofen, and glyphosate (multiple resistance) in the USA (Heap, 2018).

In the post-emergence herbicide efficacy experiment, all treatments with herbicides applied on *A. palmeri* plants had 100% control when the application was performed at the 2 to 4 leaf stage for both evaluated weed populations – Tapurah, MT (Table 7) and Ipiranga do Norte, MT (Table 8).

Treatments with applications of fomesafen, lactofen, and flumiclorac had no effective control of plants from Tapurah at 6 to 8 leaf stage; and treatments with applications of lactofen and flumiclorac were not effective to control plants from Ipiranga do Norte, MT (Tables 7 and 8).

***Table 7*** - Percentages of control and shoot dry weight of *A. palmeri* plants collected in Tapurah, MT, Brazil, at 28 days after application (DAA) of different post-emergence herbicides at two plant phenological stages

| Treatment | Rate (g ha$^{-1}$) | Phenological stages | | | |
|---|---|---|---|---|---|
| | | Control 28 DAA (%) | | Shoot dry weight at 28 DAA (g)$^{(1)}$ | |
| | | 2 to 4 leaves | 6 to 8 leaves | 2 to 4 leaves | 6 to 8 leaves |
| 01. Control | - | 0.0 bA | 0.0 dA | 0.9 bA | 0.9 dA |
| 02. Fomesafen | 125.0 | 100.0 aA | 75.8 bB | 0.0 aA | 0.5 cB |
| 03. Fomesafen | 250.0 | 100.0 aA | 94.8 aA | 0.0 aA | 0.2 aA |
| 04. Lactofen | 84.0 | 100.0 aA | 73.8 bB | 0.0 aA | 0.3 bB |
| 05. Lactofen | 168.0 | 100.0 aA | 93.8 aA | 0.0 aA | 0.1 aA |
| 06. Flumiclorac | 40.0 | 100.0 aA | 66.3 bB | 0.0 aA | 0.3 bB |
| 07. Flumiclorac | 60.0 | 100.0 aA | 45.0 cB | 0.0 aA | 0.5 cB |
| 08. Atrazine | 1500.0 | 100.0 aA | 86.3 aB | 0.0 aA | 0.2 aB |
| 09. Mesotrione + Atrazine | 120.0 + 1500.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 10. Tembotrione + Atrazine | 75.6 + 1500.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 11. Ammonium glufosinate | 400.0 | 100.0 aA | 98.3 aA | 0.0 aA | 0.1 aA |
| 12. Paraquat | 400.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 13. Saflufenacil | 49.0 | 100.0 aA | 98.3 aA | 0.0 aA | 0.1 aA |

| $F_T$ | $F_{PS}$ | $F_I$ | CV (%) | $F_T$ | $F_{PS}$ | $F_I$ | CV (%) |
|---|---|---|---|---|---|---|---|
| 115.6* | 84.8* | 11.4* | 8.7 | 24.1* | 59.7* | 3.0* | 5.3 |

* Significant by the F test at 5% probability; Means followed by the same lowercase letter in the columns or uppercase letter in the rows do not differ by the Scott-Knott test at 5% probability. (1) Original data previously transformed to $\sqrt{x+1}$. All treatments had the addition of oil at 0.5% v v$^{-1}$. $F_T$ = F of the treatments; $F_{PS}$ = F of the phenological stages; $F_I$ = F of the interaction.

***Table 8*** - Percentages of control and shoot dry weight of *A. palmeri* plants collected in Ipiranga do Norte, MT, Brazil, at 28 days after application (DAA) of different post-emergence herbicide at two plant phenological stages

| Treatment | Rate (g ha$^{-1}$) | Phenological stage | | | |
|---|---|---|---|---|---|
| | | Control 28 DAA (%) | | Shoot dry weight at 28 DAA (g)$^{(1)}$ | |
| | | 2 to 4 leaves | 6 to 8 leaves | 2 to 4 leaves | 6 to 8 leaves |
| 01. Control | - | 0.0 bA | 0.0 fA | 0.9 bA | 0.9 cA |
| 02. Fomesafen | 125.0 | 100.0 aA | 94.8 aA | 0.0 aA | 0.2 aA |
| 03. Fomesafen | 250.0 | 100.0 aA | 91.3 bB | 0.0 aA | 0.3 aB |
| 04. Lactofen | 84.0 | 100.0 aA | 78.8 cB | 0.0 aA | 0.5 bB |
| 05. Lactofen | 168.0 | 100.0 aA | 67.5 dB | 0.0 aA | 0.7 bB |
| 06. Flumiclorac | 40.0 | 100.0 aA | 47.5 eB | 0.0 aA | 0.4 bB |
| 07. Flumiclorac | 60.0 | 100.0 aA | 66.3 dB | 0.0 aA | 0.4 bB |
| 08. Atrazine | 1500.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.2 aB |
| 09. Mesotrione + Atrazine | 120.0 + 1500.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 10. Tembotrione + Atrazine | 75.6 + 1500.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.2 aA |
| 11. Ammonium glufosinate | 400.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 12. Paraquat | 400.0 | 100.0 aA | 100.0 aA | 0.0 aA | 0.1 aA |
| 13. Saflufenacil | 49.0 | 100.0 aA | 98.8 aA | 0.0 aA | 0.1 aA |

| $F_T$ | $F_{PS}$ | $F_I$ | CV (%) | $F_T$ | $F_{PS}$ | $F_I$ | CV (%) |
|---|---|---|---|---|---|---|---|
| 293.2* | 171.4* | 30.0* | 5.5 | 21.2* | 93.2* | 3.4* | 5.4 |

* Significant by the F test at 5% probability; Means followed by the same lowercase letter in the columns or uppercase letter in the rows do not differ by the Scott-Knott test at 5% probability. (1) Original data previously transformed to $\sqrt{x+1}$. All treatments had the addition of oil at 0.5% v v$^{-1}$. $F_T$ = F of the treatments; $F_{PS}$ = F of the phenological stages; $F_I$ = F of the interaction.

The correlation between accumulated shoot dry weight and weed control was linear, as shown by the correlation between treatments that had satisfactory weed control (above 80%) and their respective shoot dry weight (Tables 7 and 8). Herbicide treatments that had no satisfactory control of *A. palmeri* plants had different shoot dry weight than the control without herbicide application, but resulted in plants with potential to recover, continue to develop and, consequently, produce seeds.

Weed plants at early stages of development are more sensitive to post-emergence herbicides than more developed ones (Oliveira Junior et al., 2011). Klingman et al. (1992) also reported the importance of controlling *A. palmeri* plants with post-emergence herbicides before they reach 5 cm in height to have satisfactory control.

Fomesafen, lactofen, and flumiclorac are PROTOX inhibiting herbicides. This enzyme is responsible for the oxidation of protoporphyrinogen, generating protoporphyrin IX (chlorophyll precursors). These herbicides have little or no translocation in plants, thus, they are contact herbicides (Oliveira Junior et al., 2011). Therefore, plants with accelerated vegetative growth, such as *A. palmeri*, can quickly recover their leaf area affected by the herbicide, requiring the application of these products when the plants are small and young for a greater control effectiveness.

The occurrence of glyphosate-resistant *A. palmeri* biotypes that are also resistant to fomesafen and lactofen herbicides have been reported in Tennessee (USA) (Heap, 2018). Therefore, the use of PROTOX inhibiting herbicides requires caution to avoid increasing of resistant biotypes.

The best treatments for both evaluated weed populations were, in general, mesotrione + atrazine, tembotrione + atrazine, ammonium glufosinate, paraquat, and saflufenacil, which had control percentages greater than 98%, regardless of the weed phenological stage (Tables 7 and 8). These results indicate the importance of including maize crops in rotations with cotton or soybean crops in the areas where the *A. palmeri* seeds were collected to reduce the number of *A. palmeri* plants by using atrazine, for example. In addition, ammonium glufosinate is an alternative herbicide to control this species in areas intended for total killing of plants, directed spraying, or with ammonium glufosinate-resistant plants.

Peterson et al. (2017) conducted a field experiment in Kansas (USA) to evaluate alternative herbicides to glyphosate for controlling of *A. palmeri* after wheat harvest and found that paraquat and saflufenacil herbicides were better for the control of this weed than other herbicides, such as dicamba, and 2,4-D.

Considering the experiments conducted and the populations of *A. palmeri* evaluated in the present study, the effectiveness of the herbicides applied in pre emergence is dependent on the soil texture. The treatments with applications of flumioxazin, S-metolachlor, isoxaflutole, and trifluralin had satisfactory control regardless of the soil texture; sulfentrazone and metribuzin herbicides were effective in the sandy soil, diuron was effective in the clayey soil, and clomazone was not effective to control *A. palmeri* plants neither of the studied soils. In post emergence, all herbicides controlled both *A. palmeri* populations when applied on plants at the early development stage.

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