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Introduction and management of *Amaranthus palmeri* in Brazil

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Abstract: Glyphosate-resistant palmer amaranth, *Amaranthus palmeri,* a difficult to control weed with aggressive growth, capable of causing large yield losses in annual crops, was identified in Brazil, in the state of Mato Grosso, in 2015. After notification, an epidemiological survey was carried out to identify the place of entry and area of dispersion. Containment and eradication measures were quickly established by state and federal phytosanitary authorities through legislative measures. After identification, it was classified as a quarantine weed under official control. The Palmer amaranth Containment and Eradication Committee was established in order to support the phytosanitary defense agencies in the actions to combat the weed. State agricultural inspectors were trained to identify the species and survey the State. Actions aimed at the farmers were also carried out, highlighting the importance of identification, control and awareness. The weed was found in six municipalities in 10 farms in Mato Grosso. The importation of a used cotton harvester from the United States of America and its internal transit were found to be the main route of entry and spread of the weed. The weed spread to the State of Mato Grosso do Sul, in 2022 and was detected in two municipalities and six properties. A detailed survey is on progress. It is necessary to understand movement routes and establish measures to contain it. Effective measures regarding the importation and cleaning of used machinery needs to be adopted to avoid weed seed dispersal, and Federal legislation is needed to contain and eradicate the weed.

Keywords: Glyphosate; Herbicide resistant; Harvester; Spreading

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1. Introduction

Much of the grain production area in Brazil borders other countries that also produce soybeans, maize and cotton, such as Argentina, Uruguay, Paraguay, and Bolivia (Figure 1). The potential for introducing agricultural pests from bordering countries is considerable. In South America, the presence of *A. palmeri* was initially verified in Argentina in 1984 (Covas, 1984). It was believed that, since it was found in Argentina, the southern region in Brazil would be its likely route of introduction to the country. After detecting the presence of glyphosate-resistant (GR) *Amaranthus palmeri* (GRAP) in Argentina in 2013 (Morichetti et al., 2013), the department of agriculture and research institutions in Brazil began to worry about the possibility of this harmful species entering the country. Brazilian borders are often made up of landmarks or rivers, among agriculturally important states such as Rio Grande do Sul, Santa Catarina, Paraná, Mato Grosso, and Mato Grosso do Sul. The international spread of weeds is facilitated by the proximity between agricultural production areas in Brazil and neighboring countries. Contrary to all expectations, the first detection of *A. palmeri* in Brazil took place officially in the state of Mato Grosso in 2015, a region far from the Argentine border (Figure 1) (Andrade Jr et al., 2015).

The State of Mato Grosso is the major soybean, corn and cotton producer in Brazil, harvesting 45, 47 and 5 thousand tons, respectively, in the growing season of 2022/2023 year (Companhia Nacional de Abastecimento, 2023). Corn sowing predominantly occurs just after early soybean cultivation on the same area. Soybean is sown between September and November and corn is sown between January and March. The State of Mato Grosso is also responsible for approximately 71% of the cotton cultivation area in Brazil which is also sown as alternative to corn after soybean.

Two hypotheses were raised as a possible route of introduction in Brazil. The first was related to the use of a cotton harvester from Argentina, and the second was about the importation of used cotton harvesters from the USA. Information from the Brazilian Ministry of Agriculture and Livestock (MAPA) indicates that many cotton combines used in Brazil are imported as used equipament from United States.

Figure 1 - Brazil (white) and continental parts of neighboring countries

According to the growers' perceptions, the presence of *A. palmeri* began to be noticed in the 2011/2012 harvest, after the machines arrived from the USA when farmers noted escape of the weed from glyphosate (personal communication, Omar Roberto da Silveira determined September 2022). In an investigation by Gaines et al. (2021), the genetic similarity among *A. palmeri* from Brazil (4 populations), Argentina (10 populations), Uruguay (3 populations) and the USA (9 populations). They observed great similarity between the U.S. and Brazilian weeds. Argentine biotypes have distinct molecular and physiological characteristics, not found in the newly arrived Brazilian population. This fact made the second hypothesis more feasible. Imports of used cotton harvesters from the USA are mainly from the state of Georgia. This American state is characterized by being one of the main cotton producers and the location of the first detection of GR palmer amaranth biotype in 2004 (Culpepper et al., 2006). Soybean and maize areas in Brazil range from small farms, common to the southern region of Brazil, to large ones, common in central Brazil. Machine rental occurs with frequency and enhances the spread of weeds by the harvester's transit throughout the country. Unlike most of states, cotton is also grown as alternative to corn in Mato Grosso state.

Another important feature in Brazil is the possibility of sowing two or even three crops a year. The intense use of land in a tropical area leads to a high weed infestation pressure with high use of herbicides and, consequently, more rapid evolution of herbicide-resistant weeds than in temperate weather. In 1996, transgenic GR soybean began to be cultivated illegally in Brazil with seeds brought from Argentina. Cultivation of this crop with Brazilian government approval did not occur until 2005 (Lucio et al., 2019). GR soybean allowed farms to use glyphosate to control weeds resistant to other herbicides such as: acetolactase synthase (ALS), acetylCoA carboxylase (ACCase), and protoporphyrinogen oxidase (PPO) inhibitors. With the introduction of GR soybeans, there was a false impression that, from then on, all weed problems would be solved. Nonetheless, as in the USA, GR weed biotypes evolved soon after adoption of GR soybeans. A study conducted in 2017, showed that 20.1 million ha of soybean in Brazil contained GR populations of *Lolium multiflorum*, *Conyza* spp. and *Digitaria insularis* (Adegas et al., 2017). According to the authors, the average cost of weed resistance management in Brazil, just for the soybean production system, was estimated to range from 1.0 to 1.8 billion US$, considering the losses caused by weed competition. Thus, any new case of resistant weeds, exotic or native, has resulted in increased management difficulties and economic impact, especially when it comes to a species like *A. palmeri*.

2. *Amaranthus* species in Brazil

In Brazil, 10 species of *Amaranthus*, locally called caruru, exist (Senna, 2015). The most frequent species are: *A. deflexus*, *A. retroflexus*, *A. hybridus* (*paniculatus* and *patulus* varieties), *A. spinosus* and *A. viridis* (Kissimann, Groth, 1999). They are well adapted to the agricultural environment with uneven germination, high mass production, rapid growth, prolific seed production, high genetic variability, and with great potential to cause yield losses in commercial crops (Inoue et al., 2015). The coexistence of these species with crops has been manageable, contrary to problems involving herbicide-resistant biotypes of *Conyza* species and *Digitaria insularis*, which aggressively infest large areas. This situation can change quickly, in view of what happened in the United States, where *A. palmeri*, went from being a minor problem to the most problematic and difficult to control weed in a short period of time (Ward et al., 2013, Chahal et al., 2015). This behavior is similar to *A. hybrydus* and *A. palmeri* in Argentina, which rapidly became two of the worst weeds (Tuesca et. al., 2016). The management of *Amaranthus* species in soybean involves around 20 herbicide active ingredients registered by the MAPA (Ministério da Agricultura e Pecuária, 2022). Those herbicides are classified by different mechanisms of action such as auxin

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mimics, inhibitors of microtubule formation, cell division, PPO, ALS, enolpyruvyl shikimate phosphate synthase (EPSPS), glutamine synthetase (GS), and photosystem II (PSII), as well as photosystem I electron diverters (PSI) (Brasil, 2022). Although this information may give the impression of a comfortable control situation, the potential phytosanitary risk associated with these species cannot be underestimated. Proof of this is that, in 2018, the first case of *A. hybridus* with multiple resistance to glyphosate and chlorimuron was reported in the state of Rio Grande do Sul (Oliveira et al., 2019) with a high level of resistance to both herbicides. Areas with the presence of *A. hybridus* resistant to herbicides with the same mechanisms of action were also found in Paraná state (Resende et al., 2021).

3. Glyphosate-Resistant *Amaranhus palmeri* (GRAP) in Brazil

In the last 40 years, weed science in Brazil has evolved significantly with a great number of scientists in public and private institutions dedicated to teaching and research. Brazil is a tropical country with intensive agriculture and escalating weed problems. Unlike other states, cotton is commonly harvested in Mato Grosso following the soybean crop, often with the use of imported, used cotton harvesters. The identification of GRAP, common name in Brazil cauru-palmeri (Gazziero, Silva, 2017), occurred during a herbicide-resistant weed survey program in the cotton areas of Mato Grosso state. The case was reported in the International Herbicide-Resistance Database in 2015 (Heap, 2022). It was also confirmed by others that the introduced biotypes were resistant to glyphosate and ALS-inhibiting herbicides (Gonçalves Netto et al., 2016; Küpper et al., 2017). The state and federal phytosanitary authorities were notified and immediately adopted measures to eradicate *A. palmeri*. After notification, the state and federal phytosanitary agencies established emergency measures to eliminate these plants. GRAP plants were uprooted by hand weeding, removed from the area and incinerated before setting seeds (Figures 2, 3, 4).

4. Case confirmation

The primary outbreaks of GRAP were located in the municipalities of Ipiranga do Norte and Tapurah, in the mid-north region of Mato Grosso (MT) state (Bagolin et al., 2016). Around the outbreaks, within a radius of 20 km, the MAPA and the Institute of Agricultural Defense of the State of Mato Grosso State (INDEA/MT) carried out a survey, detecting only one focus, which involved three surrounding farms. On these farms, the infested areas were 10,000, 500 and 15 ha. Confirmation of *A. palmeri* was made after analyzing the plants in a laboratory certified by MAPA. Simultaneously, MAPA and INDEA/MT carried out an epidemiological survey, aiming to discover possible areas of dispersion of the weed. Through this survey, it was determined that the harvester used in one of the infested areas spread it to two other municipalities in the state, Campos de Júlio and Sapezal (Figure 5).

Source: Bagolin et al. (2016)

Figure 2 - Herbicide-resistant Palmer amaranth (*Amaranthus palmeri*) in a cotton field in Tapurah, MT, Brazil in 2015

Source: Bagolin et al. (2016)

Figure 3 - Plants of Palmer amaranth (*Amaranthus palmeri*) after being hoed out of the field to be destroyed. Tapurah, MT, Brazil in 2015

Source: Bagolin et al. (2016)

Figure 4 - Palmer amaranth (*Amaranthus palmeri*) plants being burned in a furnace in Tapurah, MT, Brazil in 2015

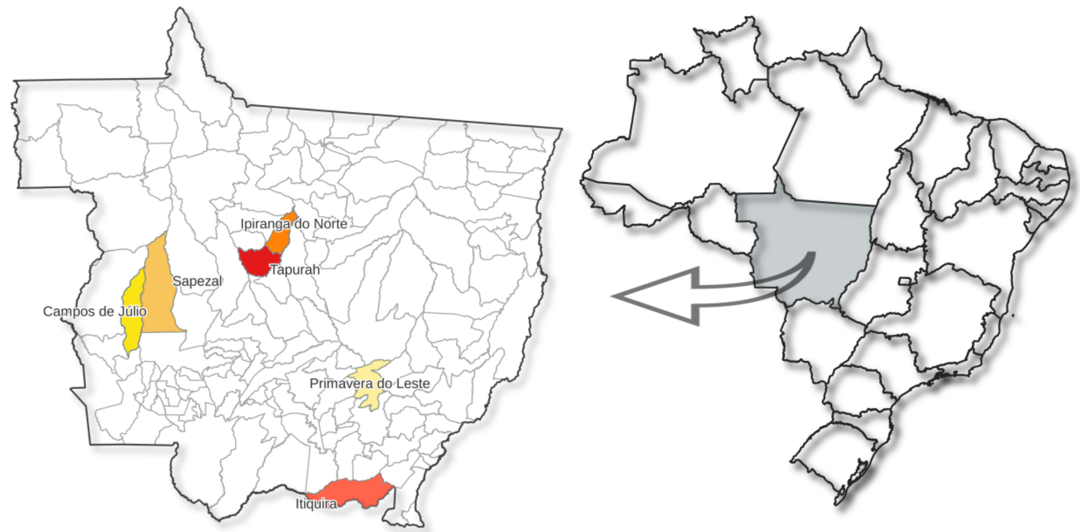

Figure 5 - Municipalities in Mato Grosso state, Brazil, highlighted by different colors, affected by Palmer amaranth (*Amaranthus palmeri*)

5. Government strategies for control

The MAPA and the INDEA-MT mobilized the Mato Grosso Institute of Cotton (IMAmt), Brazilian Association of Soybean and Corn Growers (APROSOJA-MT), the University Federal of Mato Grosso (UFMT), the University Center of Várzea Grande (Univag), and the Brazilian Agricultural Research Service (Embrapa), to combine their efforts to control the weed. These institutions joined a Work Group (WG) to devise strategies to contain and eradicate this weed.

MAPA is the federal agency responsible for coordinating all phytosanitary actions, together with the states, while INDEA-MT was responsible for implementing actions in Mato Grosso State. Together, the institutions conducted a detection survey for GRAP in the state. Inspectors were trained to identify the weed, according to guidelines generated for this purpose. In 2015, more than 1,000 farms in the state of Mato Grosso were inspected, with no detection of GRAP, except in the original outbreak farms and their surroundings. Some meetings were held with the WG for evaluation of the survey results and of the epidemiological inquiry deciding implementation of eradication measures.

A guideline (Normative Instruction INDEA-MT nº 047/2015)[1] aiming at the eradication of GRAP in Mato Grosso was published 26 days after the scientists confirmed the detection. This guideline was followed by the growers with eradication measures involving chemical control of GRAP in soybean, maize and cotton crops, mechanical control, through manual weeding, and uprooting and burning of plants found in crops. Public and private institutions met to refine the eradication measures in the set of new guidelines (INDEA-MT No. 086/2015)[2] published five months after the previous one.

A further MAPA survey was conducted to make sure that the outbreak was confined to Mato Grosso state. It also suggested prevention actions involving the public-private partnership. A virtual group was created, involving state and federal enforcement agents from across the country. In the state of Paraná, which borders Argentina and Paraguay, in addition to publications on the subject, a campaign was also launched to alert farmers and agricultural consultants about the problem (Gazziero, Silva, 2017). Other federal phytosanitary measures were adopted by MAPA and INDEA-MT to prevent further introduction or spread of GRAP to other regions of Brazil, and a quarantine pest alert was released. MAPA set up a qualified network of laboratories able to identify the species. MAPA also requested special attention from the International Agricultural Surveillance System – Vigiagro/MAPA, to comply with guidelines MAPA nº 14/2004[3], setting requirements for the import of used agricultural machinery. MAPA also held national technical meetings on GRAP with visits to outbreak farms to demonstrate the positive results obtained by the Eradication Program in Mato Grosso.

[1] Mato Grosso. Diário Oficial do Estado de Mato Grosso. Ano. CXXV, n. 26576. Instrução normativa n. 47. 2015a 33p. [acess Jul 2022] Avaliable from: <https://www.iomat.mt.gov.br/portal/edicoes/download/14131> Portuguese.

[2] Mato Grosso. Diário Oficial do Estado de Mato Grosso. Ano. CXXV, n. 26673. Instrução normativa INDEA-MT n. 86. 2015b; 98-99 [acess Jul 2022] Avaliable from: <https://www.iomat.mt.gov.br/portal/edicoes/download/14309> Portuguese.

[3] Brasil. Sistema de consulta à legislação. SISLEGIS. [acess Jul 2022] Avaliable from: <https://sistemasweb.agricultura.gov.br//sislegis/loginAction.do?method=exibirTela> Portuguese.

6. Legislation

The creation of the GRAP Eradication Program was based on the Vegetal Defense legislation of Mato Grosso state, Law nº 8.589/2006 and Decree nº 1.524/2008[4]. The final guidelines for eradication were established by INDEA-MT n 086/2015 with the following measures:

a. eradication of *A. palmeri* plants before flowering, so that they do not disperse;
b. banning crop harvesting until *A. palmeri* plants present are eliminated;
c. removal of agricultural machinery and implements from farms only after careful cleaning, and free of soil and plant residues, with prior authorization from INDEA/MT;
d. ban transit and storage of plants or part of *A. palmeri*, in Mato Grosso territory;
e. control of shipping soil samples free of weed seeds;
f. ban on the output of processing residues of plant products and cultural remains, from sites contaminated with GRAP;
g. ban the use of residues from the processing of plant products and cultural residues in animal feed;
h. ban the use of cotton and soybean by-products such as crop residues from areas infested with this pest as sources of nutrients to crops;
i. check infested plots, at intervals, not exceeding 15 days to detect the pest and its immediate destruction;
j. keep seed production field of any kind, free from this pest until harvest; and
k. Farmers in areas where the weed is detected should use all available means to prevent the reproduction of it, inside and outside the fields, under penalty of banning areas for harvesting.

At the same time, phytosanitary measures applicable outside rural farms with occurrence of the pest are:

a. communication to INDEA-MT by whoever is aware or suspects of the occurrence of this weed in Mato Grosso territory;
b. weed survey carried out by INDEA-MT;
c. banning storing suspected samples detected by INDEA-MT;
d. adoption of phytosanitary education measures of INDEA-MT;
e. inspection of agricultural machinery and implements from suspected areas;
f. seizure of plants, plant products, machinery, equipment and other materials carrying this pest;
g. disinfestation of agricultural machinery and implements from areas with occurrence of this pest;
h. destruction of plants, plant products or any other material carrying this pest;
i. sterilization and burial of infected soil samples, and;
j. authorization from INDEA-MT to conduct research involving this pest, in Mato Grosso, restricted only to infected rural property.

7. Glyphosate-resistant *Amaranthus palmeri* control

Several studies were conducted to determine chemical control alternatives based on literature information. Research was carried out with herbicides in soybean and cotton to control GRAP (Ikeda et al., 2018). These crops were sown after single and intercropped maize with marandu grass (*Urochloa brizantha* cv. Marandu, synonymous with *Brachiaria brizantha* cv. Marandu). They concluded that maize intercropping provided considerable crop mass production and helped with *A. palmeri* control.

Herbicide alternatives to glyphosate and ALS inhibitors were studied with soybean, maize, and cotton to control GRAP (Andrade Junior et al., 2018). They found good control with herbicides of several mode of action groups (Herbicide Resistance Action Committee, 2022): metribuzin, atrazine and diuron (HRAC 5); trifluralin and pedimenthalin (HRAC 3); S-metolachlor and pyroxasulfone (HRAC 15); carfentrazone, saflufenacil flumioxazin, sulfentrazone, flumiclorac, fomesafen, and lactofen (HRAC 14); glufosinate-ammonium (HRAC 10), 2,4-D and dicamba (HRAC 4), and paraquat (HRAC 22). Thus, despite the biotypes introduced in Brazil being resistant to herbicides that inhibit EPSPs and ALS, they showed that there are alternatives for adequate management of these biotypes.

8. Present status of GRAP in Brazil – Mato Grosso State

Monitoring results for GRAP in crops in the municipalities of the state of Mato Grosso are provided in Table 1. Monitoring is conducted periodically by the state phytosanitary defense agencies (INDEA-MT). After the first official detection, in June, 2015, and through the epidemiological survey, the weed was identified in four farms, two located in the municipality of Ipiranga do Norte and two in Tapurah. The estimated area of incidence in Ipiranga do Norte and Tapurah was, respectively, 650 and 11,000 ha. The municipalities of Ipiranga do Norte and Tapurah border each other. The high level of infestation in Tapurah was mainly due to wide distribution of cotton harvest residues containing *A. palmeri* seed as source of nutrients. This material was used as a source of nutrients

[4] Mato Grosso. Diário Oficial Eletrônico do Estado de Mato Grosso. Law nº 8.589/2006 and Decree nº 1.524/2008. [acess Jul 2022] Avaliable from: <https:// https://www.legisweb.com.br/legislacao/?id=133142> Portuguese.

Table 1 - Glyphosate-resistant *Amaranthus palmeri* infestations in Mato Grosso. Brazil, July 2022

Municipality	Number of farms affected by *A. palmeri*	Area (ha)	Time of detection
Ipiranga do Norte	2	650	June/2015
Tapurah	2	11,000	June/2015
Campos de Júlio	1	20	July/2016
Sapezal	1	20	July/2016
	2	50	February 2019
Itiquira	1	1,281	January/ 22021
Primavera do Leste	1	2	February/2021
Total	**10**	**13,023**	

for crops sown in succession. In the other farms, there was a low dispersion of the GRAP, which was carried out mainly by the transit of harvesters between the farms.

In the next year, in June 2016, through tracking the traffic of harvesters used in infested properties, GRAP was found to have spread in two more properties, in Campos de Júlio and Sapezal municipalities in an area in both locations of 20 ha. It was not possible to estimate the date of entry of the weed. In 2019, through the routine inspection of soybean areas conducted by INDEA-MT, two more infested farms were detected in Sapezal County. The emergence of the weed in these locations can be attributed to the sharing of a cotton harvester among farms. The dates of introduction to the two farms were not determined, but probably were close to each other. In January, 2021, again, through routine inspection carried out by INDEA-MT, the weed was detected in two more farms in two municipalities: Primavera do Leste and Itiquira, 2 and 1,281 ha, respectively. Both properties imported used cotton harvesters from the USA. The farm located in Primavera imported the machinery for the 2016/2017 harvest season and in Itiquira for the 2018/2019 season. The total infested area was then 13,023 ha (Table 1) in ten farms in six municipalities of Mato Grosso (Figure 5). A late survey conducted after those measures were applied in January, 2022 indicated a 98% reduction of infested area (personal communication, Omar Roberto da Silveira, September 2022).

The low rate of GRAP dispersion in the area deserves to be highlighted. *A. palmeri* is known to be a prolific weed seed producer, and, if not managed correctly, it can spread rapidly in crops (Ward et al., 2013). Norsworthy et al. (2017) evaluated the dispersal potential of GRAP in cotton, in four fields free of infestation, based on one resistant plant, with production of 20,000 seeds in 1 m^2. After three harvests or three growing seasons, using only glyphosate, 95 to 100% of the area was infested, making it impossible to harvest the crop. It is believed that this low rate of dispersal in Brazil may be associated with the fact that many of the infested farms rotate part of their area with the cultivation of a follow crop of maize, after soybean in the same crop season. The main cultivation system on cotton farms in Mato Grosso consists of soybean cultivation during the harvest period, followed by cotton or maize, in addition to the possibility of using cover crops during the off-season (Santos et al., 2020). Alternative herbicides are commonly used in these farms for the management of glyphosate-tolerant and resistant broadleaf weeds in soybean farms (Lucio et al., 2019). This may have contributed to delaying the rate of dispersal. The primary weed control in maize is based on the use of glyphosate in a mixture with atrazine. As mentioned earlier, atrazine is effective against GRAP.

The personal information passed on by phytosanitary inspectors who monitor infested areas indicates a perception of reduction in the population of GRAP in the properties sampled in the municipalities of Tapurah and Ipiranga do Norte. These data showed a perception of progressive reduction in the population of the remaining infestation of *A. palmeri* (November/2017 (14.0%), March/2018 (14.3%), December/2018 (7.3%) and December/2019 (1.7%). In 2020, no GRAP detection was found in the municipality of Campos de Júlio, showing the good level of cooperation among growers and government agencies on suppressing the weed.

8.1 New case of *Amaranthus palmeri* in Brazil - Mato Grosso do Sul State

Inspections of agricultural areas in Mato Grosso do Sul State (MS) in December, 2022, identified a focus of *A. palmeri* infestation in a farm located at Naviraí municipality, district of Porto Caiuá. Confirmation of species identification was performed through molecular genetics evaluation conducted by Federal Laboratory of Agricultural Defense of Goiana (LFDA-GO). The plant was located outside the farming area, close to rubble. This municipality is located on the border with the State of Paraná (Figure 6). The area was characterized by conversion of pasture areas to agriculture with extensive livestock activity and intense traffic of trucks and agricultural machinery. In February, 2023, five new foci were identified in several farms in the municipality of Aral

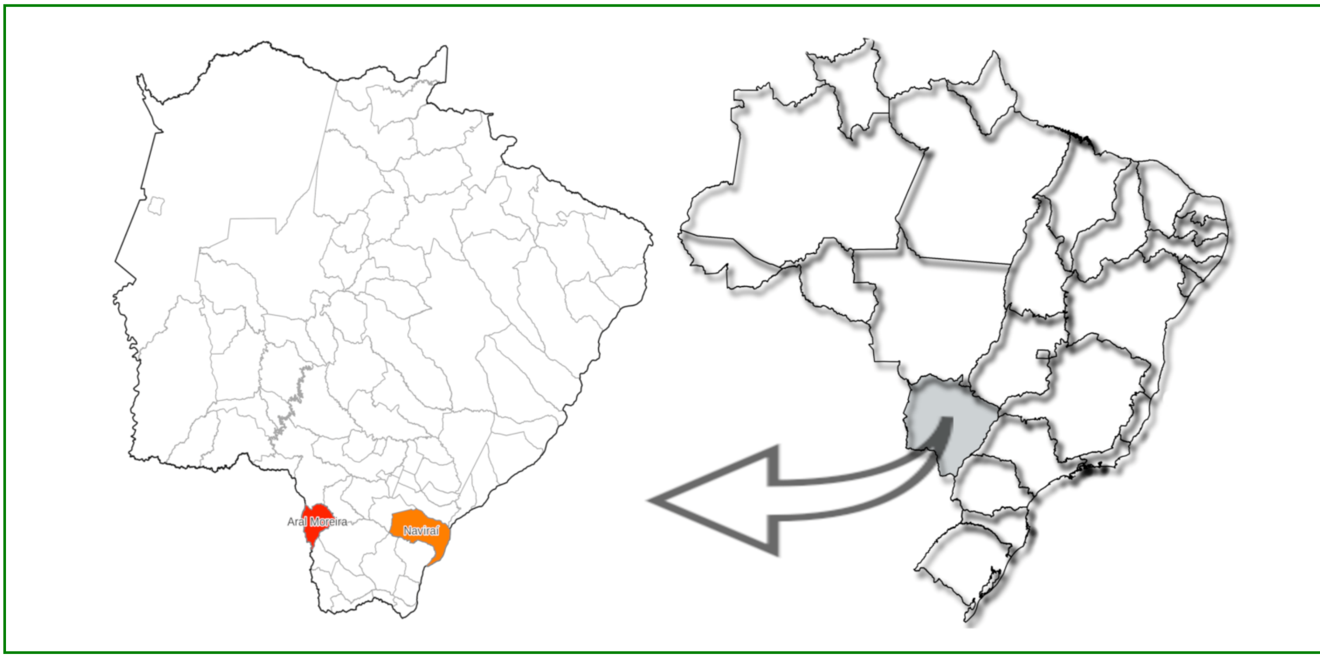

Figure 6 - Municipalities in Mato Grosso do Sul State, Brazil, highlighted by red and orange colors, affected by Palmer amaranth (*Amaranthus palmeri*)

Table 2 - *Amaranthus palmeri* infestations in Mato Grosso do Sul. Brazil, March 2023

Municipality	Number of farms affected by *A. palmeri*	Area (ha)	Time of detection
Naviraí	1	480	December/2022
Aral Moreira	5	1,180.5	February/2023
Total	**6**	**1,660.5**	

Moreira, located approximately 200 km from Naviraí, at the border with Paraguay (Figure 6).

According to a survey carried out by IAGRO, *A. palmeri* is now found in two municipalities in area of approximately 1,660 ha (Table 2). Information on the possible route of introduction of the pest in the MS State, as well as the characterization of resistance of biotypes to herbicides and genetic similarity between populations present in other parts of Brazil is being determined.

Measures to contain the weed in MS were based on four points: 1) monitoring of agricultural crops every two weeks; 2) removal of weeds from the area; 3) promoting the disinfestation of machinery on the property, before using it in other areas; 4) restricting the movement of machinery from outside the property, guideline (IAGRO-MS n 001/23)[5]. Measures were also set to standardize the movement of machines (Order IAGRO-MS nº 3694)[6]. However, overall MS State measures to contain the weed are still being drafted.

9. Containment and Eradication

The low rate of dispersion and reduction of infestation, in Mato Grosso State demonstrates that inspection actions and control measures are being effective in containing the weed. However, eradication is a complex task, especially for *A. palmeri*, which is characterized by being a prolific weed, especially when it comes to eliminating the remaining 1% of the infestation (Simberloff, 2003). Large growing areas such as Mato Grosso State make the eradication initiative difficult and laborious, besides demanding a considerable amount of time. Experience shows that the smaller the

[5] Mato Grosso do Sul. Agência Estadual de Defesa Sanitária Animal e Vegetal (IAGRO). Nota Técnica. IAGRO, nº 001/23 [acess March 2023]. Avaliable from: <OFÍCIO/SEPROTUR/IAGRO/DP 0 https://www.iagro.ms.gov.br/wp-content/uploads/2023/02/MS_NotaTecnicaIAGRO_A.palmeri_17.02.23.pdf 00/2011> Portuguese.

[6] Mato Grosso do Sul. Diário Oficial Eletrônico do Estado de Mato Grosso Sul. Law nº 6.035/2022 and Orderr nº3.694/2023. [acess March 2023] Avaliable from: <https://www.iagro.ms.gov.br/wp-content/uploads/2023/02/PORTARIA_IAGRO_3694_TransitoMaquinasAgricolas-1.pdf> Portuguese.

infested area, the greater the proportion of successful eradication cases (Rejmánek & Pitcairn, 2002).

The occurrence of other species of the genus *Amaranthus*, commonly found in soybean and cotton crops, such as *A. hybridus* and *A. retroflexus*, may complicate the identification, mainly in the control phase. Added to these factors are dispersal by wild animals and crop residues, seed dormancy, and the lack of reporting by the growers to the authorities, fearing the inspection of their farms, making it more difficult to eradicate the species. The first focus should be given to containment of dispersion and eradication treated as a medium/long term process with constant inspection of the crops. Also, the occurrence of this weed on highways and roads adjacent may contribute to the dispersal of seeds and their resistance genes (Bagavathiannan, Norsworhy, 2016).

Eradication actions for *A. palmeri* adopted by the State of Minnesota (Yu et al., 2021) were similar to those used in Brazil. Among the lessons learned, we highlight the need to establish an eradication program based on legislation with support of a management team composed by stakeholders and phytosanitary inspectors, with regular inspection of infestation sites and other municipalities in the State. It is important to establish an aggressive inspection protocol associated with the awareness of the agricultural community about the impact that the weed can cause, in addition to training in identification, management strategies and the importance of reporting suspected cases. Finally, there is a need to raise awareness in other States to inspect their areas to prevent the spread of the weed. In Minnesota, in areas where the weed had been detected in 2016 and 2017, it was considered eradicated in 2021 (Yu et al., 2021). It is important to note that despite research demonstrating the great loss of viability of *A. palmeri* seeds in soil after three years (Jha et al., 2014; Korres et al., 2018), there is still the possibility of viable seeds remaining in the area. Seed longevity in soil can make it difficult to obtain 100% control of any weed.

10. Import and machinery transit

The method of introduction of GRAP to Brazil sheds light on the important problem of the importation of used contaminated farm machinery from countries that have quarantined pests, as well as the movement of such machinery between properties, once the weed is established on a property. Despite the existence of specific legislation and rules on the importation of used farm machinery (INDEA-MT nº 14/2004), the sum of these facts demonstrates that the cleaning of machinery in the countries of origin and their inspection are not being carried out properly. Thus, inadequate inspection of imported, previously used farm machinery worldwide can result in dispersion of new species, herbicide-resistant biotypes of existing weeds, or both. The dispersion of weeds by agricultural machinery can be considered one of the main routes of spreading (Lopes-da-Silva et al., 2016). Thus, it is recommended that stricter criteria should be enforced in the process of importing and cleaning such machinery.

The internal transit of used agricultural machinery is another point of great importance to avoid the spread of pests. The absence of federal legislation that establishes standardized criteria among the states contributes to the introduction of a particular pest into a new region. Furthermore, there is an absence of rules for transport of contaminated machinery between municipalities within the same state or between farms in the same area. This fact reinforces the importance of the farmers' awareness of proper cleaning of agricultural implements before use in their fields. The transit of harvesters is characterized as one of the main ways of weed dissemination (Petit et al., 2013). During harvest, seed dispersal can occur in the area through the disposal of crop residues and spread in new areas when they are partially adhered to the cutting platform and other machinery structures. Some weed species show synchronization of their cycle with that of the crop (Benvenuti, 2007). This characteristic has contributed to the increase in the dispersion and importance of certain weed species.

11. Conclusions

GRAP was introduced to Mato Grosso State in Brazil through the importation of farm equipment contaminated with seed. Agile and effective government decision-making in compliance with phytosanitary measures, in addition to the commitment of growers, public, and private institutions to date has contributed to the containment and suppression of GRAP in infested areas. However, the recent appearance of biotypes in the State of Mato Grosso do Sul deserves attention. It is necessary to elucidate the form of introduction and dissemination in this State. It is important to reinforce and/or review the inspection policy for the importation of used machinery, mainly from countries that have quarantined weeds. Also, uniform, effective cleaning criteria among the different states should be promoted. Establishment of a federal norm for containment and eradication measures of the weed when detected is needed, with engagement of the agricultural community.

Author's contributions

All authors cooperated on the preparation of this manuscript. All authors read and agreed to the published version of the manuscript.

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