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Scientific Article

Tolerance of grain sorghum hybrids to tembotrione herbicide

Tolerância de híbridos de sorgo granífero ao herbicida tembotrione

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ABSTRACT - The scarcity of registered herbicides that are effective in controlling monocotyledonous weeds is a risk for sorghum growing in Brazil. Therefore, this study aims to evaluate the tolerance of sorghum grain hybrids to the post-emergence application of tembotrione. Two experiments were carried out in the field in the Southwest of Goiás (Santa Helena de Goiás and Montividiu). Eleven grain sorghum hybrids were evaluated in Santa Helena de Goiás and three hybrids were evaluated in Montividiu, in association with five doses of tembotrione, always with the addition of atrazine to the application mixture. Herbicide treatments were applied in post-emergence when sorghum plants had six to seven leaves developed (V_6/V_7). Sorghum hybrids showed variations in tolerance to the herbicide tembotrione, demonstrating different responses in terms of phytotoxicity, plant height, stem diameter, shoot dry biomass and yield. Tembotrione causes reductions in the yield of grain sorghum, in average percentages ranging from 25.9 to 61.9%, depending on the dose used, demonstrating that it is not selective for the crop. The results obtained indicate low potential use of tembotrione for grain sorghum at the doses evaluated, in association with atrazine, in areas of soils with both more clayey texture and sandier texture.

Keywords: Crop succession. Weeds. Yield. Selectivity. *Sorghum bicolor*.

RESUMO - A escassez de herbicidas registrados que apresentem eficácia no controle de plantas daninhas monocotiledôneas é um risco para o cultivo do sorgo no Brasil. Portanto, este trabalho tem como objetivo avaliar a tolerância de híbridos de sorgo granífero à aplicação em pós-emergência do tembotrione. Dois experimentos foram conduzidos a campo no Sudoeste de Goiás (Santa Helena de Goiás e Montividiu). Em Santa Helena de Goiás, onze híbridos de sorgo granífero foram avaliados e em Montividiu três híbridos, em associação a cinco doses do tembotrione, sempre com a adição à calda de aplicação de atrazine. Os tratamentos herbicidas foram aplicados em pós-emergência quando as plantas de sorgo estavam com seis a sete folhas desenvolvidas (V_6/V_7). Os híbridos de sorgo apresentaram variações quanto à tolerância ao herbicida tembotrione, demonstrando diferentes respostas quanto à fitointoxicação, altura de plantas, diâmetro de colmo, biomassa seca da parte aérea e produtividade de grãos. O tembotrione proporciona reduções na produtividade do sorgo granífero, em percentuais médios de 25,9 a 61,9%, a depender da dose utilizada, demonstrando não ser seletivo para a cultura. Os resultados obtidos indicam baixo potencial de uso do tembotrione para o sorgo granífero nas doses avaliadas, em associação com atrazine, tanto em áreas de solos com textura mais argilosa quanto de texturas mais arenosas.

Palavras-chave: Sucessão de culturas. Plantas daninhas. Produtividade. Seletividade. *Sorghum bicolor*.

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INTRODUCTION

Grain sorghum can be used directly in human food, in the manufacture of animal feed and in the production of biofuels, which puts this crop in the fifth place in the ranking of the most important cereals in the world. In Brazil, the cultivated area is 1,418 thousand hectares, with an annual production of approximately 4.8 million tons of grains, and Goiás is the largest producer of the cereal (CONAB, 2024), which is commonly cultivated in the second season, in succession to the soybean crop.

Sorghum is a grass with C_4 photosynthetic metabolism, highly efficient in converting solar energy and using water. Despite that, the presence of weeds becomes one of the biggest problems for obtaining high grain yields (BARARPOUR et al., 2019). This is attributed to competition for nutrients, water, and light (DILLE et al., 2020), with the critical period of prevention of weed interference in sorghum crop being 23 to 42 days after emergence (CABRAL et al., 2013).

Due to its practicality and selectivity, the chemical method is the most used in weed control in sorghum crops, being implemented almost exclusively with the use of the herbicide atrazine. However, repetitive use of this herbicide can cause infestation of grasses, such as southern sandbur (*Cenchrus echinatus*), in cultivation areas, because the herbicide in question has a preferential spectrum of control over broadleaf species (HAMID; AIYELAAGBE; BALOGUN, 2011). Therefore, interference of weeds, especially grasses, is the main problem in sorghum cultivation and can cause yield reductions of more than 60% (DILLE et al., 2020). In addition, excessive and constant use of the same herbicide can induce the selection of weed biotypes with resistance to the applied active ingredient (ABIT et al., 2009). In Brazil, five cases of weed resistance to Photosystem II-inhibiting herbicides (atrazine's mechanism of action) have already been confirmed, referring to the species *Bidens subalternans*, *Amaranthus retroflexus*, *Amaranthus viridis*, *Bidens pilosa*, and *Conyza sumatrensis* (HEAP, 2024).

Given this scenario, searching for selective herbicides should be among the priorities of research involving sorghum crop. Among the options available for use in Brazil, tembotrione stands out, which acts by inhibiting the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD), belonging to the chemical group of triketones (STEPHENSON et al., 2015). The HPPD enzyme is critical for the synthesis of plastoquinone and tocopherols (LIU; LU, 2016). Plastoquinone is in turn a cofactor in the formation of carotenoids, which are chlorophyll-protective substances in plants (JHALA et al., 2023). The absence of carotenoids, resulting from the inhibition of HPPD, causes sensitive plants to suffer oxidative damage, consequently leading to destruction of chlorophyll molecules, resulting in leaf whitening, with subsequent necrosis and death of plant tissues (VAN ALMSICK, 2009).

Based on the site of action, HPPD-inhibiting herbicides were classified as belonging to Group 27 by the Weed Science Society of America (WSSA) and Group F2 by the Herbicide Resistance Action Committee (HRAC) (MALLORY-SMITH; RETZINGER, 2017). In Brazil, this herbicide is registered only for use in maize crop. It is important to emphasize that tembotrione has better control of weeds than atrazine (WILLIAMS et al., 2011), thus being an important complement to the action of this herbicide already in traditional use in the sorghum crop.

The herbicide to be registered for use and recommended for a given crop must have selectivity, and there may be variations between genotypes of the same species (CROZIER et al., 2024). Therefore, it is essential that the evaluation of selectivity of a given herbicide be carried out in different cultivars of the same crop. In view of this problem, it is hypothesized that sorghum hybrids will show different responses to the post-emergence application of the herbicide tembotrione, with some hybrids demonstrating greater tolerance compared to others. This variation in tolerance may be related to genetic differences between hybrids, causing different levels of leaf damage and growth after tembotrione application. In addition, improving weed management in sorghum is extremely important for increments in yield and sustainability of the crop in Brazil. Thus, this study aimed to evaluate the tolerance of sorghum hybrids to the post-emergence application of the herbicide tembotrione.

MATERIAL AND METHODS

Two experiments were conducted in the field in the second season (off-season), from March to July 2016, in succession to soybean. One experiment was carried out in the municipality of Santa Helena de Goiás (17°42'67" S; 50°26'37" W and 540 m altitude) and the other was conducted in Montividiu (17°19'57" S; 51°18'51" W and 802 m altitude), both important in sorghum production and located in the southwestern region of Goiás state, Brazil.

According to Köppen's classification, the climate of the region where the experiments were set up is tropical (Aw), with a dry period in winter and rainfall concentrated in summer (CARDOSO; MARCUZZO; BARROS, 2015). It is worth pointing out that the two municipalities, despite being located in the same region, are distinguished by their altitudes, which influences the average temperature and rainfall distribution throughout the development of the crop. The average rainfall and temperature of the municipalities of Santa Helena de Goiás and Montividiu are 1,539 mm and 24.3 °C and 1,512 mm and 23.0 °C, respectively (CLIMATE-DATA, 2024). Rainfall data collected during the experiments are presented in Figure 1.

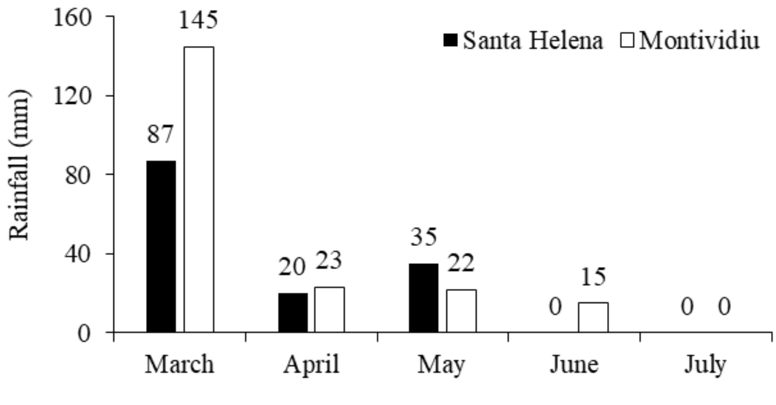


Figure 1. Rainfall data (mm) collected during the period of the experiments. Santa Helena de Goiás and Montividiu, GO, Brazil, 2016.

In Santa Helena de Goiás, the experiment was conducted in a *Latossolo Vermelho escuro distrófico* (Oxisol) (SANTOS et al., 2018). Soil samples were collected in the 0.0-0.2 m layer to determine the physical-chemical characteristics, and the following results were obtained: pH in $CaCl_2$: 5.24; Ca, Mg, K, Al, H + Al, CEC and SB: 2.37, 1.22, 0.34, 0.05, 4.79, 8.72 and 3.93 $cmol_c$ dm^{-3}, respectively; P: 2.41 mg dm^{-3}; Cu, Zn, Fe and Mn: 4.96, 2.61, 102.09 and 127.05 mg dm^{-3}, respectively; Organic matter: 28.99 g dm^{-3}; clay, silt and sand: 471, 135 and 394 g kg^{-1}, respectively (clayey textural class).

The soil of the experiment conducted in Montividiu was classified as *Latossolo Vermelho amarelo distrófico* (Oxisol) (SANTOS et al., 2018). Soil samples were also collected in the 0.0-0.2 m layer, and the following results were obtained: pH in $CaCl_2$: 5.35; Ca, Mg, K, Al, H + Al, CEC and SB: 1.98, 0.50, 0.10, 0.01, 2.10, 4.68 and 2.58 $cmol_c$ dm^{-3}, respectively; P: 14.37 mg dm^{-3}; Cu, Zn, Fe and Mn: 1.47, 8.65, 54.02 and 58.45 mg dm^{-3}, respectively; OM: 15.46 g dm^{-3}; clay, silt and sand: 119.1, 16.7 and 864.2 g kg^{-1}, respectively (loamy sand textural class).

In Santa Helena de Goiás, the treatments were arranged in an 11 x 5 factorial scheme, which consisted of eleven grain sorghum hybrids (BRS 330, BRS 380, DKB 540, DKB 590, Jade, MS 320, Ranchero, XB 6020, XB 6022, 80G20 and A 9904) associated with five doses of the herbicide tembotrione (0, 60, 120, 180 and 240 g ha^{-1}). For all doses, the herbicide atrazine (1,000 g ha^{-1}) was added to the application mixture, in addition to the adjuvant methyl ester of soybean oil at a concentration of 0.1%. In the experiment conducted in Montividiu, a 3 x 5 factorial scheme was used, and the treatments were composed of the combination of three sorghum hybrids (AG 1085, BRS 330 and Jade) and the same five doses of tembotrione in association with atrazine and adjuvant, as described for the experiment of Santa Helena de Goiás.

Both experiments were set up in a randomized block design with four replicates. The experimental units were formed by four rows spaced 0.5 m apart, 6.0 m long, making a total area of 12.0 m^2. The usable area corresponded to 5.0 m^2, being formed by the two central rows, disregarding 0.5 m from the ends of the plot.

In both experiments, the sowing furrows were mechanically opened, and the sorghum hybrids were manually sown in the first half of March at 3 cm depth. At ten days after sowing, thinning was carried out in order to obtain a population of 200,000 plants per hectare for all hybrids in the two experiments. Fertilization, either basal or top-dressing, was not carried out in the experiments, in accordance with the cultivation system adopted in the region, since this practice was done only at the planting of the soybean crop (predecessor crop).

Herbicide treatment applications followed the same methodologies in both locations, carried out in post-emergence when sorghum plants were in the V_6/V_7 development stages (sixth to seventh expanded leaf, respectively). Applications were carried out using a CO_2 pressurized knapsack sprayer, equipped with a bar with four 110.02 spray tips, with double fan and air induction, spaced 0.5 m apart. The working pressure used was 2.0 kgf cm^{-2}, resulting in a spray volume equivalent to 150 L ha^{-1}. The climatic conditions recorded during the application in Santa Helena de Goiás and Montividiu showed average temperatures of 28.0 and 24.2 °C, wind speed of 3.1 and 4.1 m s^{-1} and relative humidity of 44.6 and 48.0%, respectively.

Regardless of the action of the herbicides applied, the experimental units of the two experiments were maintained without weed interference by means of manual weeding, in order to leave sorghum plants exposed only to the effect of the herbicide treatments. There was no need to carry out actions to control pests or diseases, since the incidence of these organisms did not reach levels of economic damage, hence not justifying the intervention with management practices.

Phytotoxicity in sorghum plants was visually evaluated at 2, 7, 14 and 28 days after herbicide applications (DAA). In these evaluations, percentage scores were assigned, where zero corresponds to the absence of symptoms and 100 corresponds to the death of all plants present in the usable area of the experimental unit (GAZZIERO, 1995).

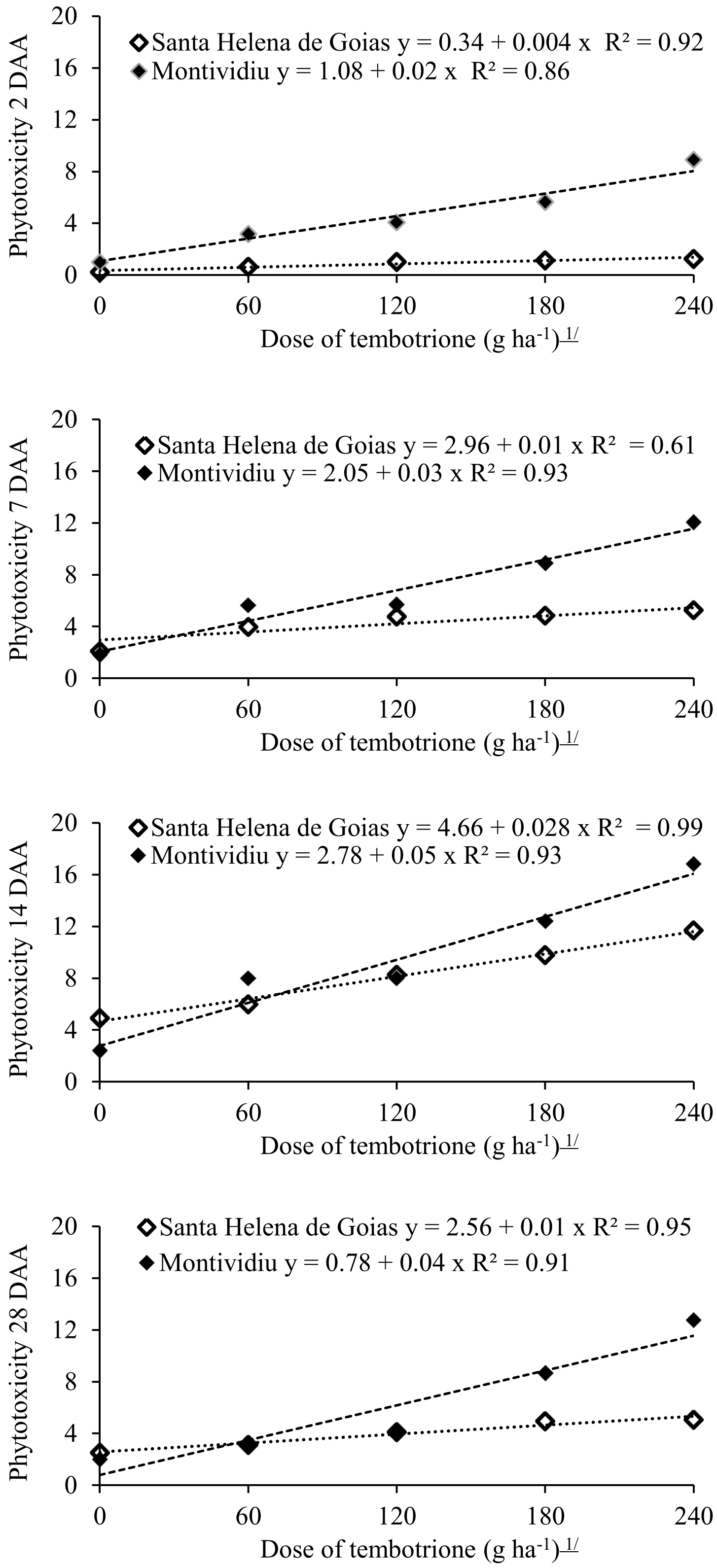
At the time of harvest, the following evaluations were carried out in the usable area of the plots: plant height (measured from the collar to the upper end of the panicle); stem diameter (measured with a digital caliper, at the first node above the soil surface); and shoot dry biomass (measured by weighing the plant material on a precision scale, after complete drying of the aerial part of the plants in a forced air circulation oven, regulated to 65 °C); these evaluations were carried out on five plants per plot. In addition to these variables, grain yield was also determined (harvesting and threshing of all panicles present in the usable area, followed by cleaning and weighing of the grains with moisture content corrected to 13%).

The data were evaluated separately for each location. The percentages of phytotoxicity were transformed according to the expression $\sqrt{x+1}$. Subsequently, analysis of variance was performed for the obtained data, applying the F test at 5% significance level. When the effects of single factors or interactions were significant, Tukey test at 5% probability level was performed to compare the means of sorghum hybrids, and regression analysis was performed to compare the means of herbicide doses. The analyses were performed using the statistical software Sisvar (FERREIRA, 2019).

RESULTS AND DISCUSSION

In both locations, no interaction was observed between the doses of the herbicide tembotrione, associated with atrazine, and the grain sorghum hybrids for the visual evaluations of phytotoxicity. This implies that there is no differential tolerance between the sorghum hybrids as a function of the doses of tembotrione used. Despite being recommended in Brazil for post-emergence applications, tembotrione has residual activity in the soil and is also recommended for use in pre-emergence in other countries (RANI; DUHAN; TOMAR, 2020).

The physicochemical characteristic of this herbicide molecule associated with the soil type may have contributed to the absence of interaction in relation to the differential tolerance between sorghum hybrids subjected to different doses of the herbicide. Weak acidic herbicides, such as tembotrione (pKa of 3.18), when applied in soils with pH > pKa (Santa Helena de Goiás - pH: 5.24; Montividiu - pH: 5.35), tend to be more available in the soil solution, which facilitates the absorption of the molecule by sorghum plants, which may increase the initial levels of phytotoxicity, even at low doses, and thus mask possible differential responses between the hybrids evaluated. However, the effect of tembotrione on the phytotoxicity of sorghum plants can be seen when evaluating the dose factor. Regardless of the location, there was a linear increase in phytotoxicity with the increase in the doses of the herbicide tembotrione associated with atrazine, with more accentuated levels in the Montividiu experiment (Figure 2).



[1/] Treatments applied in association with atrazine (1,000 g ha^{-1}). * Significant fit at 5% probability level.

Figure 2. Phytotoxicity of grain sorghum visually evaluated after post-emergence application of increasing doses of the herbicide tembotrione associated with atrazine.

The highest levels of phytotoxicity were observed at 14 DAA at a dose of 240 g ha^{-1} (12 and 16% for Santa Helena de Goiás and Montividiu, respectively). In general, at 28 DAA, sorghum plants already showed recovery from the symptoms caused by the herbicide, especially in the experiment conducted in Santa Helena de Goiás. The higher phytotoxicity levels observed in sorghum plants cultivated in Montividiu may have also been influenced by soil texture, although the applications were carried out in post-emergence. In sandy soils, the herbicide tends to be less absorbed to mineral colloids, which leaves it at higher concentrations in the soil solution and, consequently, more available to be absorbed (EL-SAEID; ALGHAMDI, 2020). Increased phytotoxicity of sorghum plants with the increase in tembotrione doses was also found by Cunha et al. (2016) when the herbicide was applied in post-emergence (eight-leaf stage), but at a higher level than that found in the present study.

In Santa Helena de Goiás, differences were observed regarding the tolerance of the grain sorghum hybrids to the herbicide tembotrione applied in post-emergence in all evaluations (Table 1). The only exception was the evaluation carried out at 2 DAA, in which all hybrids had injury symptoms at very low levels. At 7 DAA, phytotoxicity was more intense in the hybrids BRS 330, DKB 540 and 80G20, which changed in the following evaluation (14 DAA), in which the hybrids BRS 330, Jade, XB 6022 and A 9904 had greater symptoms of phytotoxicity. In the last evaluation (28 DAA), all hybrids showed recovery from the symptoms caused by the herbicide. However, the group with the highest apparent tolerance to the association between tembotrione and atrazine was composed of MS 320, Ranchero, and 80G20.

Table 1. Phytotoxicity of grain sorghum hybrids after post-emergence application of the herbicide tembotrione associated with atrazine.

Hybrids	Phytotoxicity (%)			
	2 DAA	7 DAA	14 DAA	28 DAA
	Santa Helena de Goiás			
BRS 330	0.95 A	6.65 b	10.65 b	5.35 b
BRS 380	0.70 A	4.45 a	7.60 a	4.05 b
DKB 540	0.80 A	5.60 b	6.65 a	4.10 b
DKB 590	0.85 A	3.85 a	8.35 a	4.85 b
Jade	0.80 A	3.05 a	10.30 b	3.60 b
MS 320	1.05 A	3.60 a	6.45 a	2.50 a
Ranchero	0.95 A	3.65 a	6.00 a	2.25 a
XB 6020	0.70 A	3.70 a	7.50 a	4.55 b
XB 6022	0.70 A	2.55 a	9.60 b	5.10 b
A9904	1.30 A	3.95 a	10.10 b	4.00 b
80G20	0.70 A	5.25 b	6.30 a	3.05 a
CV (%)	15.47	28.59	24.37	23.74
	Montividiu			
AG 1085	3.70 A	6.85 a	10.15 a	4.20 a
BRS 330	4.95 A	6.55 a	8.30 a	4.60 a
Jade	5.05 A	7.00 a	9.85 a	9.70 b
CV (%)	17.71	20.83	19.29	17.82

Means followed by the same letter in the column do not differ from each other by the Scott-Knott criterion at 5% probability level. CV (%): coefficient of variation.

In the experiment conducted in Montividiu, differences in the sensitivity of the sorghum hybrids were detected only in the evaluation at 28 DAA (Table 1). This can be attributed to the smaller number of genotypes evaluated in this locality, associated with the fact already mentioned that, in sandier soils, such as the one found in Montividiu, tembotrione tends to be more available in the soil solution, being more easily absorbed by plants, and thus making it difficult to visualize a differential tolerance between sorghum hybrids. Although the phytotoxicity values were very low in this period, the hybrid Jade, as in Santa Helena de Goiás, still showed more pronounced symptoms, higher than those verified in the hybrids AG 1085 and BRS 330 in Montividiu, demonstrating less capacity to recover from injuries. The phytotoxicity symptoms observed were characterized by an initial mild discoloration of the leaves (“albinism”), evolving to a reddish hue, and causing, in some cases, necrosis of the affected tissues, similar to those described by Damalas et al. (2017).

In both experiments, the height of grain sorghum plants was influenced only by the genotypic characteristics of the hybrids evaluated and was not influenced by the application of the association between the herbicides tembotrione and atrazine (Table 2). In pearl millet, a reduction of less than 10% in plant height was observed with the use of tembotrione, and this reduction was proportional to the increase in herbicide doses (DAN et al., 2010a). In Santa Helena de Goiás, the hybrids were divided into four groups according to plant stature. The tallest hybrids were BRS 330, XB 6020 and A 9904 hybrids, while the shortest hybrid was DKB 590.

Table 2. Plant height, stem diameter and shoot dry biomass of grain sorghum hybrids.

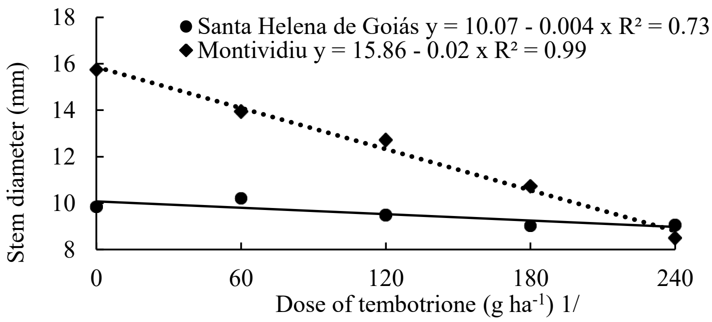
Hybrids	Plant height (cm)	Stem diameter (mm)	Dry biomass (g pl^{-1})
		Santa Helena de Goiás	
BRS 330	84.5 a	11.2 a	44.8 b
BRS 380	77.2 b	7.6 d	37.3 b
DKB 540	73.2 c	9.9 b	40.0 b
DKB 590	62.2 d	10.3 b	40.3 b
Jade	71.7 c	9.5 b	42.8 b
MS 320	72.9 c	10.8 a	49.8 a
Ranchero	76.3 b	8.8 c	45.0 b
XB 6020	80.7 a	8.7 c	37.5 b
XB 6022	77.0 b	10.6 a	57.3 a
A 9904	79.0 a	8.5 c	39.8 b
80G20	76.6 b	8.3 c	40.0 b
CV (%)	9.91	14.97	32.45
		Montividiu	
AG 1085	109.0 a	13.7 a	-
BRS 330	111.0 a	9.9 b	-
Jade	96.6 b	13.3 a	-
CV (%)	5.42	4.22	-

Dry biomass (g $plant^{-1}$) - Montividiu					
Hybrids	Doses of tembotrione (g ha^{-1})				
	0	60	120	180	240
AG 1085	113.7 c	86.2 b	80.0 b	71.3 b	61.3 b
BRS 330	165.0 a	122.5 a	107.5 a	88.8 a	61.2 b
Jade	143.7 b	125.0 a	108.7 a	93.8 a	74.3 a
CV (%)			6.31		

Means followed by the same letter in the column do not differ from each other by the Scott-Knott criterion at 5% probability level. CV (%): coefficient of variation.

In general, the sorghum hybrids showed higher plant height in the Montividiu experiment compared to the one conducted in Santa Helena de Goiás (Table 2). In this location, the hybrids AG 1085 and BRS 330 were the tallest ones. It should be noted that Montividiu is a place of higher altitude compared to Santa Helena de Goiás. As a consequence, milder temperatures are recorded, especially at night, which favors greater growth of sorghum plants (SUNOJ et al., 2020). Although there are differences in plant height in each location, the low values of plant stature stand out (below 85 and 115 cm for Santa Helena de Goiás and Montividiu, respectively). This constitutes an advantage in terms of plant lodging, which was not observed in any of the hybrids in both locations.

In the experiments conducted in Santa Helena de Goiás and Montividiu, the stem diameter of grain sorghum plants decreased with the increase in the doses of the herbicide tembotrione associated with atrazine, regardless of the hybrid evaluated, but this effect in Santa Helena de Goiás was of small magnitude (Figure 3). Also, the hybrids differed in relation to stem diameter. Hybrids BRS 330, MS 320 and XB 6022 were the ones with the highest values in Santa Helena de Goiás, while AG 1085 and Jade were the ones with the largest diameter in Montividiu (Table 2). It is known that plants with thin basal stems have a lower capacity for translocation of water, nutrients and photoassimilates and are also more susceptible to lodging (MATEUS et al., 2011). However, this was not observed in the experiments, as mentioned earlier.



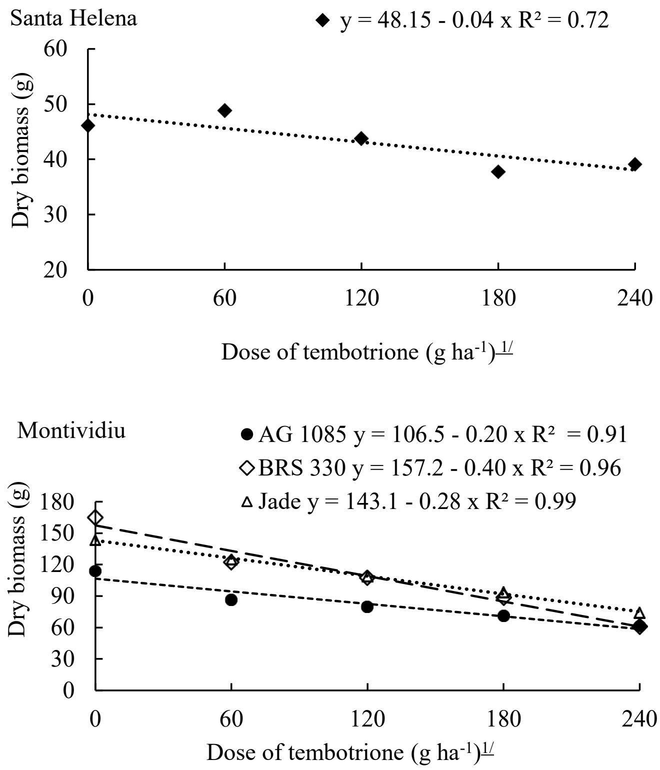
Treatments applied in association with atrazine (1,000 g ha-1). * Significant fit at 5% probability level.

Figure 3. Stem diameter of grain sorghum plants after post-emergence application of increasing doses of the herbicide tembotrione.

The dry biomass accumulated in the shoots of sorghum plants in the experiment of Santa Helena de Goiás decreased with the increase in the doses of the herbicide tembotrione, regardless of the hybrid evaluated (Figure 4). Similar effects were observed in Montividiu, with a greater decrease for the hybrid BRS 330. As in grain sorghum, high susceptibility of sweet sorghum hybrids to tembotrione in the accumulation of fresh mass is also reported in the literature (TEIXEIRA et al., 2017).

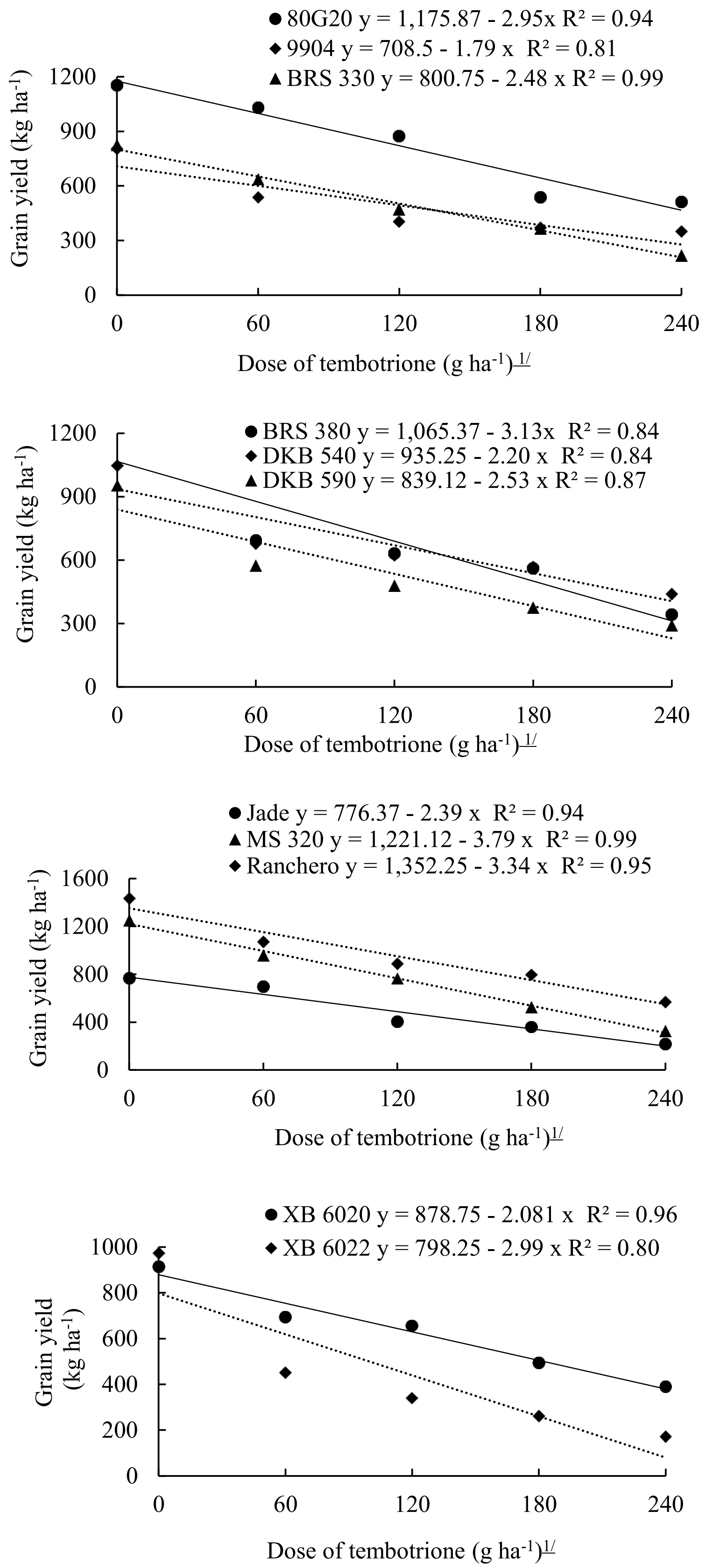
The grain sorghum hybrids showed differences in dry biomass accumulation in Santa Helena de Goiás, regardless of the application of tembotrione associated with atrazine. In this location, the hybrids MS 320 and XB 6022 were superior to the others for this parameter and were also the ones with the largest stem diameters, as previously reported (Table 2). In Montividiu, grain sorghum hybrids behaved differently when exposed to different doses of tembotrione. For all the doses evaluated, AG 1085 always showed lower shoot dry biomass compared to the hybrids BRS 330 and Jade, not differing only from BRS 330 for the dose of 240 g ha^{-1}.

All grain sorghum hybrids evaluated in the two experiments showed decreases in grain yield with the increase in the doses of tembotrione associated with atrazine, but in different magnitudes (Figures 5 and 6 for Santa Helena de Goiás and Montividiu, respectively). In general, the yield reductions were already accentuated from the lowest evaluated dose of the herbicide (60 g ha^{-1}). These results corroborate those reported by Dan et al. (2010b), who observed that the phytotoxicity caused by tembotrione significantly reduced grain yield in the grain sorghum hybrid AG 1040.



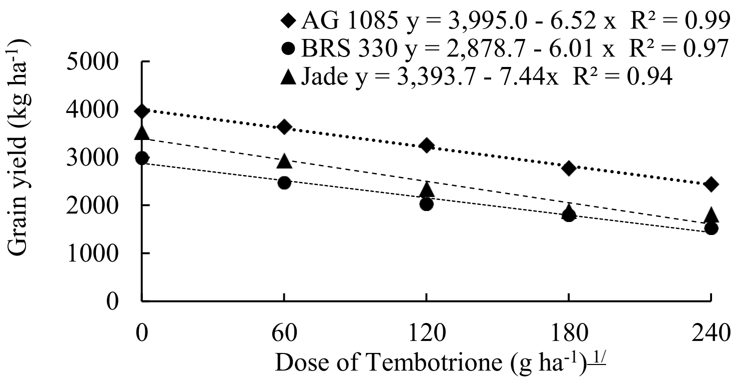
1/ Treatments applied in association with atrazine (1,000 g ha-1). * Significant adjustment at 5% probability.

Figure 4. Shoot dry biomass of grain sorghum hybrids after post-emergence application of increasing doses of the herbicide tembotrione.



[1/] Treatments applied in association with atrazine (1,000 g ha^{-1}). * Significant fit at 5% probability level.

Figure 5. Grain yield of grain sorghum hybrids after post-emergence application of increasing doses of the herbicide tembotrione associated with atrazine.



[1/] Treatments applied in association with atrazine (1,000 g ha^{-1}). * Significant fit at 5% probability level.

Figure 6. Grain yield of grain sorghum hybrids after post-emergence application of increasing doses of the herbicide tembotrione associated with atrazine.

Analysis of the data obtained in Santa Helena de Goiás showed that the hybrid Ranchero was the one with the highest grain yield when tembotrione was not used (Table 3). On the other hand, the hybrids MS 320, Ranchero and 80G20 stood out when subjected to the application of 60 and 120 g ha^{-1} of tembotrione, the latter dose being the one that is close to the recommended for use in the maize crop. Similar performances for the hybrids Ranchero and 80G20 were obtained at the highest dose (240 g ha^{-1}), whose results were similar to those of DKB 540 and XB 6020. It is worth highlighting the values obtained with the hybrid Ranchero, which was the only one with the highest grain yield at the dose of 180 g ha^{-1}.

The grain yield values obtained in Santa Helena de Goiás at doses of 60 and 120 g ha^{-1} of tembotrione indicate lower sensitivity of the hybrids MS 320, Ranchero and 80G20 to the herbicide. On the other hand, at the highest dose, the hybrids BRS 330, Jade and XB 6022 were the ones with the lowest grain yield. Additionally, it was observed that, from the dose of 180 g ha^{-1} of tembotrione for the same locality, the grain yields of each hybrid were greatly reduced compared to the treatment without herbicide application.

Table 3. Grain yield (kg ha^{-1}) of sorghum hybrids after post-emergence application of increasing doses of the herbicide tembotrione.

Hybrids	Doses of tembotrione (g ha^{-1})				
	0	60	120	180	240
			Santa Helena de Goiás		
BRS 330	825 d	637 b	472 c	367 c	218 c
BRS 380	1,217 b	693 b	631 b	561 b	342 b
DKB 540	1,046 c	677 b	622 b	567 b	439 a
DKB 590	952 c	574 c	480 c	375 c	290 b
Jade	767 d	695 b	406 c	359 c	215 c
MS 320	1,250 b	959 a	765 a	525 b	328 b
Ranchero	1,433 a	1,072 a	887 a	796 a	568 a
XB 6020	913 c	693 b	656 b	493 b	389 a
XB 6022	974 c	450 c	339 c	261 c	171 c
A 9904	804 d	536 c	404 c	370 c	349 b
80G20	1,153 b	1,029 a	873 a	537 b	512 a
CV (%)			16.48		
			Montividiu		
AG 1085	3,962 a	3,637 a	3,250 a	2,775 a	2,437 a
BRS 330	2,987 c	2,462 c	2,025 c	1,793 b	1,518 c
Jade	3,525 b	2,931 b	2,343 b	1,887 b	1,812 b
CV (%)			4.47		

Means followed by the same letter in the column do not differ from each other by the Scott-Knott criterion at 5% probability level. CV (%): coefficient of variation.

In Montividiu, the hybrid AG 1085 proved to be the most productive under all doses of tembotrione evaluated, including the control treatment without the use of this herbicide (Table 3). On the other hand, the hybrid BRS 330 was the one that had the lowest grain yield, matching Jade only at the dose of 180 g ha^{-1} of tembotrione. These two hybrids were also the ones with the lowest grain yields in Santa Helena de Goiás from the dose of 120 g ha^{-1} of tembotrione.

In general, the yields obtained in Montividiu were much higher than those obtained in Santa Helena de Goiás, regardless of the use of tembotrione. Factors such as lower night temperatures, due to higher altitude, and higher volume of rainfall during the development of the hybrids, especially in the grain filling period (Figure 1), may explain the higher grain yield in Montividiu (DJANAGUIRAMAN et al., 2014).

The results obtained in the experiments conducted in the Southwest region of Goiás indicate a low potential for use of the herbicide tembotrione for the grain sorghum hybrids available, at the doses evaluated in post-emergence applications (development stages V_6/V_7) in association with atrazine, in areas of soils with both more clayey texture and sandier texture. In addition to the contribution of genetic improvement to the development of tembotrione-tolerant lines and hybrids (PANDIAN et al., 2020), applications of this herbicide in earlier stages of sorghum plants (V_2 to V_4) should be evaluated in future studies, in order to enable the use of tembotrione in sorghum crop and thus provide an alternative for more efficient chemical control of grasses, in addition to mitigating the selection of weed biotypes with resistance to atrazine.

CONCLUSION

Sorghum hybrids show variations in tolerance to the herbicide tembotrione associated with atrazine, demonstrating different responses regarding phytotoxicity, plant height, stem diameter, shoot dry biomass and grain yield. In addition, the herbicide tembotrione, at all the doses evaluated, causes reductions in the grain yield of the grain sorghum hybrids evaluated, in average percentages ranging from 25.9 to 61.9%, demonstrating that it is not selective to the crop.

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