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Thidiazuron and Ethyl-trinexapac Affect Upland Rice Irrigated by Sprinkler Irrigation

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Abstract

Rice is a prominent crop in Brazil. Its cultivation predominates in flooded areas in the South region of the country. However, the upland rice grown in the Midwest Region is a viable option for a sustainable expansion in the country. It still results in a grain yield lower than that of flooded cultivation, and there are constant problems with crop lodging, especially in areas using sprinkler irrigation. Thus, new ways to increase grain yield and minimize upland rice lodging are critical. The objective of this study is to verify the effects of thidiazuron and ethyl-trinexapac on the rice culture and verify whether the simultaneous use of both results in a beneficial interaction. The work was carried out in Selvíria, MS, using the cultivar BRS Esmeralda in the agricultural years 2015/16 and 2017/18. The experimental design was randomized blocks in a 2 × 4 factorial design with four replications. The treatments were combinations of application of the plant regulator thidiazuron at a fixed dose of 1.0 g ha^{-1} (presence or absence) and four doses of the growth regulator ethyl-trinexapac (0, 50, 100 and 150 g ha^{-1}). Thidiazuron did not affect grains yield. Ethyl-trinexapac reduced plant height and eliminated lodging. The simultaneous use of both regulators did not affect the rice culture regarding the analyzed variables.

Keywords: BRS Esmeralda, cytokinin, lodging, plant regulators

1. Introduction

Rice is one of the most cultivated cereals in the world. Rice is native from Asia and comprises the diet of more than half of the world population (Cantrell, 2002; Kumar & Ladha, 2011). As a basic constituent of Brazilians' food menu, Brazil corresponds to the non-Asian country that most produces and consumes rice. Therefore, rice occupies a prominent position in the national agricultural scenario (Rice, 2014). In Brazil, there is a predominance of rice cultivation in the southern region using flood irrigation system however this type of cultivation is limited because it causes a high environmental impact and a high water demand (Heinemann & Stone, 2009). Among the possible environmental impacts are the native vegetation elimination and alteration of microflora and regional fauna, fish production, insect population and erosion and sedimentation conditions in the watershed. In addition, in Brazil, it was noted problems arising from the use of herbicides in flood irrigation rice as part of it circulates through the trays and returns to streams (Bernardo, 1997).

Thus, uplands cultivation in the Central-West region becomes a viable alternative for the expansion of rice crops (Kluthcouski et al., 1991; Embrapa, 2006). It is important to remember that upland rice cultivation occurs in places with an adequate rainfall regime or under a sprinkler irrigation system and includes from large mechanized to small farms with subsistence production (Ferreira & Lacerda, 2018).

On the other hand, this type of cultivation has two disadvantages: the first is the reduced grain yield in relation to the southern region, mainly due to occasional Indian summers (Mendes et al., 2014). To overcome this problem, one option is to use sprinkler irrigation, which provides production stability and profitability and encourages the adoption of high technology practices for greater crop production using limited water resources (Crusciol et al., 2012). However, this entails the second disadvantage of upland cultivation: an exaggerated development of plant height and, as a consequence, lodging, hindering the harvest and reducing the grain yield and the quality of the grains (Arf et al., 2012). This is because with sprinkler irrigation the rice plants develop more and reach higher heights, making them much more susceptible to bedding (Rodrigues, Soratto, & Arf, 2004; Vela et al., 2013).

Due to the lower grain yield of upland rice in relation to flooded crops in the southern region, the search for ways to leverage grain yield in the Brazilian Cerrado becomes inevitable. Recently, it has been found that the application of thidiazuron (TDZ) in the culture may be a possibility for obtaining this increase in grain yield. Alves et al. (2015) observed a 23.5% increase in yield of the BRS Esmeralda cultivar using 0.9 g ha^{-1} of the product, due to the higher number of spikelets per panicle, higher fertility of spikelets and greater mass of 100 grains caused by the TDZ application.

With respect to plant regulators, there are those that can be used to reduce plant height and to minimize the problem with the plant lodging, as is the case of ethyl-trinexapac (Buzetti et al., 2006; Campos, Ono, & Rodrigues, 2009). Works on this regulator have shown that it reduces an exaggerated growth of plant height, with little or no detriment to grain yield (Nascimento et al., 2009; Arf et al., 2012; Martins, 2018).

Nascimento et al. (2009), when testing ethyl-trinexapac doses (0, 75, 150, 225 and 300 g ha^{-1} a ia) at three application times (active tillering, between active tillering and floral differentiation and floral differentiation) in the Primavera rice cultivar, concluded that the 150 g ha^{-1} dose applied during floral differentiation provided a reduction in plant height and elimination of lodging without damaging grain yield. This experiment was carried out in the municipality of Selvíria-MS, in an area planted with corn in the previous agricultural year, which spent the winter in fallow and was prepared mechanically. Irrigation of the area was by a fixed sprinkler irrigation system with 3.3 mm h^{-1} flow rate in the sprinklers.

Arf et al. (2012) developed another work in the same region of Selvíria, under the same previous work (including soil preparation and irrigation), but using ethyl-trinexapac doses (0, 50, 100, 150 and 200 g ha^{-1} of ia) applied on the occasion of floral differentiation in the cultivars Caiapó (traditional type), BRS Primavera and BRS Soberana (intermediate type) and IAC 202 (modern type). The authors concluded that the application of 50 g ha^{-1}, 100 g ha^{-1} and 150 g ha^{-1} of ethyl-trinexapac in the cultivars Caiapó, BRS Soberana and BRS Primavera, respectively, reduced plant height and eliminated lodging; while for the cultivar IAC 202 there was no need for the growth regulator because it did not present lodging. In the case of the cultivars Caiapó and BRS Primavera, the regulator application in the appropriate dose benefited crop yield.

Martins (2018) evaluated ethyl-trinexapac doses (0.0, 37.5, 75.0, 112.5 and 150.0 g ha^{-1} of ia) and application times (6th, 7th and 8th fully formed leaf on the main stem) in upland rice cultivar BRS Esmeralda. The experimental area was located in the municipality of Selvíria-MS, on Cerrado soil, prepared in a conventional way and irrigated by a fixed sprinkler irrigation system with a mean precipitation of 3.3 mm $hour^{-1}$ in the sprinklers. In this work, all parcels that did not receive the application of the regulator have suffered lodging. The author concluded that the application of the 75 g ha^{-1} dose on the occasion of the seventh rice leaf is the best considering the reduction of plant height and lodging, without grain yield reduction.

In view of the above, the present work was formulated to verify the best dose of ethyl-trinexapac to be applied in the BRS Esmeralda cultivar when the application time is defined as the floral differentiation (different from that adopted by Martins, 2018); to verify if the TDZ application would result in increases in rice yield and still if the TDZ use would suppress the possible damages of the higher doses of ethyl-trinexapac in the yield of the culture. This work aims to verify the effects of thidiazuron and ethyl-trinexapac on the produciton components and upland rice yield irrigated by sprinkler irrigation and, at the same time, verify whether the simultaneous use of both results in a beneficial interaction for the upland rice.

2. Material and Methods

This work was developed during the agricultural years of 2015/16 and 2017/18 at the Unesp Teaching, Research and Extension Farm-Campus de Ilha Solteira, located in the municipality of Selvíria, MS (approximately at 51°24′ W and 20°20′ S, average altitude of 350 m).

The experimental area is characterized by a Typical Dystrophic RED LATOSOL, with a clayey texture (Santos et al., 2013), originally occupied by Cerrado vegetation and conventional agricultural crops. The soil chemical analysis of the area in the 0-20 cm layer, performed according to Raij et al. (2001), resulted in the following characteristics for the first year: Presin = 33 mg dm^{-3}, OM = 21 g dm^{-3}, K, Ca and Mg = 3.4, 20 and 13 mmolc dm^{-3}, respectively; pH, Al and H+Al = 5.3, 0.0 and 34 mmolc dm^{-3}, respectively; S-SO_4 = 2 mg dm^{-3}, CEC =

70.4 mmolc dm^{-3} and V = 52%. For the second year, the results were Presin = 16 mg dm^{-3}, OM = 21 g dm^{-3}, K, Ca and Mg = 1.8, 28 and 18 mmolc dm^{-3}, respectively; pH, Al and H+Al = 5.2, 0.0 and 31 mmolc dm^{-3}, respectively; S-SO_4 = 6 mg dm^{-3}, CEC = 78.8 mmolc dm^{-3} and V = 61%.

According to ALVARES (2013) and the Köppen classification, the climate of the region is Aw, with an average annual rainfall of 1,322 mm and an average annual temperature of 23 °C. Figure 1 shows data of rainfall and minimum and maximum air temperature in the two years of the experiment.

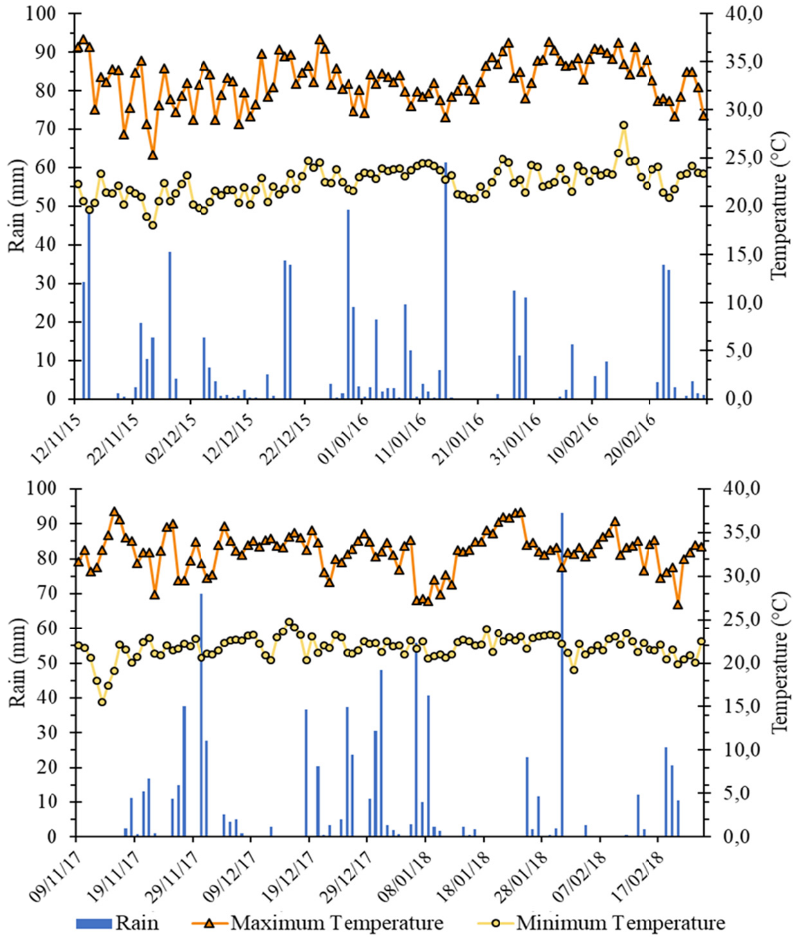

Figure 1. Climatic data for both rice crops. Selvíria, MS (2015/16 and 2017/18)

Source: Canal Clima (2018).

The experiment was randomized blocks in a 2 × 4 factorial design with four replications. Thus, the treatments were the combination of the application or not of the plant regulator thidiazuron at a fixed dose of 1.0 g ha^{-1} (presence or absence) at the time of crop tillering, and four doses of ethyl-trinexapac (0.0, 50.0, 100.0, 150.0 g ha^{-1}) at the time of floral differentiation. The plots consisted of five rows of five meters in length with a spacing between rows of 0.35 m. The useful area considered were only the three central rows of each plot.

In both the harvest of 2015/16 and 2017/18, the mechanical preparation of the experimental area was carried out by plowing and two harrowings. Subsequently, the mechanized sowing was carried out set for a seeding density of 70 kg ha^{-1}. In the first year, the sowing occurred on November 12, 2015, with the subsequent emergence of plants on November 17, 2015. In the second year, the sowing occurred on November 9, 2017, and the emergence on November 16, 2017. In both years of experiment, seed treatment was carried out using pyraclostrobin + methyl thiophanate + fipronil (5 + 45 + 50 g of a.i. 100 kg^{-1} of seeds) for the control of termites (family Isoptera, with emphasis on the species *Procornitermes triacifer* and *Syntermes molestus*, according to Borém & Rangel, 2015), cornstalk borer (*Elasmopalpus lignosellus*) and pathogenic fungi in the initial period of crop development. The fertilization performed in the sowing furrow in the first year was 150 kg ha^{-1} of 08-28-16 of the N-P-K formulation, and in the second year was 250 kg ha^{-1} of 08-28-16. Soon after sowing, during both years of experiment, the pre-emergence herbicide pendimetalin (1,400 g ha^{-1} a.i.) was applied. The herbicide was diluted in water and sprayed on the whole area with a syrup volume of 200 L ha^{-1}, soon after sowing the rice.

The cultivar was BRS Esmeralda, which is characterized by a high grain yield and grain quality, good tolerance to water stress, high hardiness and good "stay green". Its productive potential is higher than 7,000 kg ha^{-1} and its average grain yield is 4,050 kg ha^{-1}. It has an approximate maturity cycle of 105-110 days (Embrapa, 2013).

A standard sprinkler irrigation system consisting of a motor pump, PVC pipes (Tigre®) and Mankad® sprinklers with 3.3 mm h^{-1} flow rate was used to provide water to meet the water of crop demand. Irrigation management was based on three crop coefficients (Kc) distributed in four periods between emergence and harvest: 0.40 for the vegetative phase; two values for the reproductive phase (initial 0.70 and final 1.00); and the reversion of these two values at the next stage of maturation (Rodrigues et al., 2002). For the correct irrigation management, the crop evapotranspiration needs to be estimated and one way to do this is from the crop coefficient curves (Kc), which reflect variation rates of water use according to the growth phases. (Benlin et al., 2006).

The cover fertilization was carried out in the first year by applying 40 kg ha^{-1} of N at 17 days after the emergence of the crop (DAE) using ammonium sulphate as the source, and 50 kg ha^{-1} of N + 50 kg ha^{-1} of K_2O at 48 DAE using the formulation 20-00-20 (N-P-K). In the second year, nitrogen fertilization was performed in a single time, at 33 DAE, using 60 kg ha^{-1} of N as ammonium sulfate (Raij et al., 1997). In both years, soon after fertilization, irrigation was carried out, providing a water blade of approximately 15 mm. The weeds were controlled during post-emergence with the application of 2.2 g ha^{-1} of metsulfuron methyl at 21 DAE in the first year and at 19 DAE in the second year. In the first year of cultivation, two manual weed removals were required after post-emergence application to perform a good weed control. During both years of experiment, an insecticide was used to control the stink bug (thiamethoxan, 25 g ha^{-1}) and a fungicide was used as a preventive measure for blister (trifloxystrobin + tebuconazole, 100+200 g ha^{-1}).

The application of thidiazuron was performed using a costal hand sprayer with a TX-VS2 conical nozzle and an approximate volume of 300 L ha^{-1}. In the first year, this operation was carried out at 29 DAE and, in the second year at 27 DAE during plant tillering. Later, during floral differentiation, the differents ethyl-trinexapac doses (0.0; 50.0; 100.0; 150.0 g ha^{-1}) were applied under the spraying conditions similar to thidiazuron. In the first year, it occurred at 49 DAE, and in the second year at 41 DAE. The experimental plots were harvested manually in two central lines of each experimental plot at 100 DAE in the 2015/16 crop and at 103 DAE in the 2017/18 crop. Then, the harvested material was mechanically tracked. The grains were removed and placed in paper trays for natural drying in the shade, so that the level of moisture of the sample became closer to 13%.

The following evaluations were carried out during the conduction of the experiment: Plant height (at the end of the cycle, measured the distance between the plant base and the end of its highest panicle in 10 random plants within each plot useful area); Degree of lodging (obtained by visual observations at the maturation phase using the following scores: (0) no lodging; (1) up to 5% of lodged plants; (2) between 5 and 25% of lodged plants; (3) between 25 and 50% of lodged plants; (4) between 50 and 75% of lodged plants; (5) between 75 and 100% of lodged plants); Number of panicles per m^2 (determined by counting the number of panicles in 1.0 m of row of plants in the useful area of the plots and then calculated per square meter); Total number of grains per panicle (obtained by counting the number of grains of 15 panicles collected at the moment of the evaluation of the number of panicles per square meter in each plot); Number of filled or unfilled grains per panicle (determined by counting the number of filled grains and unfilled of 15 panicles after separating them through an airflow); Mass of 100 grains (evaluated through random collection and weighing of two samples of 100 grains of each plot - 13% wet basis); Grain yield (determined by weighing the grains in bark in the useful area of the plots, correcting the humidity to 13% and converting it into kg ha^{-1}); Hectoliter mass (evaluated on a special scale for hectoliter mass, water content of grains corrected to 13% (wet basis), using two samples per plot).

The results were submitted to F test. When the F test was significant ($p < 0.01$ and $p < 0.05$), a comparison of means for the application of thidiazuron and a polynomial regression for ethyl-trinexapacdoses was carried out. The statistical program SISVAR® was used to perform statistical analyses (Ferreira, 2011). For the analysis of the data obtained for lodging degree, the previous transformation of the same ones was realized following the equation $y = (x + 0.5)^{0.5}$ (that is, the notes determined in field were summed with 0,5 and the result was raised to 0.5).

3. Results and Discussion

Plant height and lodging were not affected by the application of thidiazuron at a fixed dose of 1.0 g ha^{-1} (Table 1). In the same way, the application of this same plant regulator by Alves et al. (2015) in two rice cultivars (BRS Esmeralda and IAC 202) also did not affect plant height regardless of the time of application and the dose of TDZ used.

Dario et al. (2004) obtained similar results by applying a phytoregulator containing auxin, cytokinin and gibberellin in rice in a flood irrigation system; plant height was not affected. More recently, Buzo et al. (2018), working with doses of TDZ applied at crop tillering and the cultivar ANa 5015, also did not observe a significant effect on plant height. However, Garé et al. (2017), also working with doses of TDZ applied in the cultivar ANA 5015, noticed that the regulator affected plant height. The data fitted a quadratic regression equation, presenting a maximum height point when the dose of 0.41 g ha^{-1} of the product was used. Thus, the effects of TDZ on plant height appear to be uncertain. The plant height stems from the intensity of cell divisions that occur in the apical meristem and the subsequent elongation of new cells. Considering the biological function of cytokinins in plants, they are substances capable of stimulating cell division and, therefore, may promote a greater shoot growth (Taiz & Zeiger, 2013). Wright (1966) observed that the application of exogenous cytokinins in wheat coleoptiles resulted in a further elongation of cells.

Thus, the application of TDZ as an exogenous cytokinin would be expected to affect plant height in this work. This did not occur. It can be explained because the application of exogenous cytokinin does not result in significant effects on plants when the endogenous level of this hormone is already at a sufficient quantity for the plant (it rarely occurs in limiting quantities), as state Salisbury and Ross (2013). In this same sense, Garé et al. (2017) consider that different rice cultivars have different levels of expression of the gene cytokinin oxidase (an enzyme that degrades endogenous cytokinin). Therefore, there are different responses to the exogenous application of this regulator. The authors claim that it is possible that the cultivar BRS Esmeralda has a low expression of this gene and, therefore, a low degradation of cytokinin. This would explain the difference of TDZ effects on plant height in the aforementioned studies.

Table 1. Mean values for plant height, lodging scores and panicles m^{-2} of cv. BRS Esmeralda in function of the application of thidiazuron and doses of ethyl-trinexapac. Selvíria, MS (2015/16 and 2017/18)

Treatments	Height (m)		Panicles m^{-2}		Lodging Scores[a]	
	15/16	17/18	15/16	17/18	15/16	17/18
Thidiazuron (T)						
Thidiazuron	0.93	1.09	221	290	0	1.25
Nontreated	0.91	1.07	218	292	0	1.25
Doses of Ethyl-trinexapac (D)						
0.0	1.04[1]	1.20[2]	236	283	0	5.00b
50.0	0.94	1.14	221	304	0	0.00a
100.0	0.89	1.06	218	281	0	0.00a
150.0	0.80	0.92	203	294	0	0.00a
F Test						
T	1.08 ^{ns}	0.60 ^{ns}	0.04 ^{ns}	0.03 ^{ns}	-	0.00 ^{ns}
D	22.99**	35.87**	1.68 ^{ns}	0.80 ^{ns}	-	228.91**
T × D	0.55 ^{ns}	0.09 ^{ns}	0.50 ^{ns}	0.35 ^{ns}	-	0.00 ^{ns}
SMD	0.04	0.04	21.16	24.05	-	-
CV	6.49	5.27	13.11	11.25	-	12.71
General Mean	0.92	1.08	219.63	290.71	0	1.28

Note. [a]Scores: (0) no lodging; (1) up to 5% of lodged plants; (2) between 5 and 25% of lodged plants; (3) between 25 and 50% of lodged plants; (4) between 50 and 75% of lodged plants; (5) between 75 and 100% of lodged plants. Statistical analysis performed after data transformation for $y = (x + 0.5)^{0.5}$; ns = not significant at the $P \leq 0.05$ level; ** = significant at 1% probability by F test; SMD = significant minimum difference; CV = Coefficient of Variation (%). Means followed by the same letters do not differ by Tukey test (5%).

[1] $y = -0.0015x + 1.0326$ ($R^2 = 98.17\%$);

[2] $y = -0.0018x + 1.2165$ ($R^2 = 96.42\%$).

On the other hand, the application of doses of ethyl-trinexapac affected plant height, so that the data fitted a linear regression equation in both years of cultivation. As can be observed, for both years, the behavior was the same: the higher the dose, the lower the plant height. This is the purpose of applying this growth regulator to the crop, as long as it does not affect the crop's yield. After all, as seen, the reduction of plant height may reduce or eliminate the occurrence of lodging and, consequently, the problems arising from it.

Buzo et al. (2018) observed a reduction of 0.09 m in rice plant height by the application of 50 g ha^{-1} of ethyl-trinexapac during floral differentiation. Nascimento et al. (2009), working with three application times and different doses of ethyl-trinexapac in the cultivar Primavera, concluded that the application at floral differentiation of 150 g ha^{-1} of the a.i. was the best option for the reduction of plant height without hindering crop yield. In their work, this treatment resulted in a plant height 0.39 m shorter than the control.

Arf et al. (2012), working with different doses of ethyl-trinexapac (0.0-200 g ha^{-1}) in four upland rice cultivars (BRS Primavera, Caiapó, BRS Soberana and IAC 202), observed that the data obtained for plant height fitted linear regression equations for all cultivars. The cultivar Caiapó, for example, decreased its height by 0.63 m with the application of the maximum dose (200 g ha^{-1}) in relation to the control.

In this study, there was a decrease of 0.24 m in plant height in the first year of cultivation (2015/16) and of 0.28 m in the second year (2017/18) in relation to the maximum dose of 150 g ha^{-1} and the control without ethyl-trinexapac. This is the expected result of ethyl-trinexapac, since, according to Taiz and Zeiger (2013), this growth regulator inhibits the formation of active gibberellins, causing plants to synthesize and accumulate biologically less efficient gibberellins, reducing cell elongation and, consequently, plant height.

In the first year, no lodging was observed in any of the plots. Therefore, it was not possible to observe the effects of ethyl-trinexapac on lodging. However, in the second crop, the plants developed more. They became heavier and there was lodging, but only in the plots that did not receive the application of ethyl-trinexapac. This reinforces the idea that ethyl-trinexapac is extremely useful for the reduction of losses by upland rice lodging. The statistical analysis for the second year lodging scores was given by the ANOVA of the transformed data and, as we can see, there was a significance for the doses of ethyl-trinexapac. The results only indicated that there was total lodging in the plots without regulator and absence of lodging in plots with regulator, evidencing that the treatment without ethyl-trinexapac differs from the treatments using the regulator, regardless of the dose.

Arf et al. (2012) reported that the application of the lowest dose of ethyl-trinexapac (50 g ha^{-1}) eliminated lodging only in cv. Caiapó; in cvs. BRS Primavera and BRS Soberana, higher doses were required to eliminate lodging. In the work by Nascimento et al. (2009), when the application of ethyl-trinexapac was tested during floral differentiation, the lodging was only eliminated using doses higher than 75 g ha^{-1}.

With regard to the amount of panicles m^{-2}, this variable was not affected either by the application of TDZ at a fixed dose nor by the doses of ethyl-trinexapac applied. Alves et al. (2015), Garé et al. (2017) and Buzo et al. (2018) did not observe significant effects of the application of thidiazuron at crop tillering when working with the cultivars BRS Esmeralda, IAC 202 and ANa 5015, which corroborates the findings of this work.

There are studies demonstrating that cytokinins induce a greater development of lateral meristems and the breakdown of dormancy of these lateral buds in vine and apple trees, facilitating the proliferation of multiple shoots in some cultures (Gairi & Rashid, 2004; Srivatanakul et al., 2000), including rice (Yookongkaew, Srivatanakul, & Narangajavana, 2007), beans (Mohamed et al., 2006) and wheat (Shan et al., 2000). In addition, these substances may stimulate rice plant tillering by promoting the development of the buds of these tillers (Liu et al., 2011). Moreover, the work by Zulkarnain et al. (2013) reported the occurrence of an increase in the number of tillers and panicles in rice plants in a saturated soil in function of the application of cytokinin. Such information would contradict the results obtained in this work, which, in turn, corroborate those observed by Alves et al. (2015), Garé et al. (2017), and Buzo et al. (2018). However, Alves et al. (2015) state that it is possible that such application did not affect the number of panicles m^{-2} because it was made after defining the number of buds that would originate tillers in the rice plant.

Regarding both this information and that already mentioned, according to which the plant may not respond to the exogenous application of cytokinin when its endogenous levels are sufficient for its development (Salisbury & Ross, 2013), there is an explanation coherent with the results found here. Thus, it may be necessary to carry out assays involving moments of application of TDZ before the full crop tillering using different cultivars or even under stressful conditions, which would result in plants with an insufficient endogenous level of cytokinins. Thus, it may be possible to better understand how TDZ act on rice plants and benefit the crop.

With regard to ethyl-trinexapac, the doses applied at floral differentiation did not affect the number of panicles m^{-2} in both years. The literature presents different data regarding the effects of growth regulators on the number of panicles per m^2. Alvarez et al. (2014), working with doses of three growth regulators, among them ethyl-trinexapac, observed that with increasing doses (maximum of 200 g ha^{-1}), there was a linear reduction in the number of panicles per m2, more sharply when it came to ethyl-trinexapac. Among the four rice cultivars used by Arf et al. (2012), only the cv. IAC 202 had the number of panicles m^{-2} affected by regulator doses. The other three cvs. were not affected as to this characteristic regardless of the dose applied. Finally, the work by Nascimento et al. (2009) shows that, regardless of the time of application of the regulator, the doses applied affected the number of panicles per m^2, but the data fitted a linear increasing function, that is, the increase in the dose of ethyl-trinexapac (maximum of 300 g ha^{-1}) was capable of benefiting this variable. These differences in results evidence that the effects of the growth regulator depends on the timing and application doses, as well as on the cultivar (Dunand, 2003; Rajala & Peltonen-Sainio, 2001), and maybe even on environmental characteristics that vary from year to year.

The number of filled grains was affected by the application of thidiazuron at the fixed dose of 1.0 g ha^{-1} in both years (Table 2). The number of unfilled grains and total grains, in turn, were only affected by the application of this regulator in the first year of the experiment (2015/16 harvest). In all these situations, the behavior was the same: the application of the regulator reduced the number of grains per panicle. This result differs from all others found in the scarce literature on the use of TDZ in upland rice cultivation. Alves et al. (2015) obtained an increase in the number of spikelets per panicle of the cv. BRS Esmeralda in function of the doses applied. The crop tillering time was the best time for application. The authors also stated that the maximum dose used in their work (0.9 g ha^{-1}) provided a 13.4% increase in the number of spikelets per panicle in relation to the control treatment. On the other hand, the works by Garé et al. (2017) and Buzo et al. (2018) showed that the application of TDZ doses at the time of rice crop tillering did not affect the amount of filled grains, unfilled grains and total grains per panicle. It is worth remembering that both studies mentioned used the cultivar ANa 5015, different from the cv. BRS Esmeralda used in this study, which may justify the difference in results.

Table 2. Average values for filled grains, grains unfilled grains and total grains per panicle of cv. BRS Esmeralda in function of the application of thidiazuron and doses of ethyl-trinexapac. Selvíria, MS (2015/16 and 2017/18)

Treatments	**Filled**		**Unfilled**		**Total**	
	15/16	**17/18**	**15/16**	**17/18**	**15/16**	**17/18**
Thidiazuron (T)						
Thidiazuron	127b	125b	24b	38	150b	163
Nontreated	147a	141a	27a	35	174a	176
Doses of Ethyl-trinexapac (D)						
0.0	141	125	22[1]	49[2]	163	174
50.0	138	137	24	40	162	178
100.0	139	139	25	24	163	163
150.0	131	132	30	32	161	165
F test						
T	12.84**	4.36*	6.09*	1.02 ^{ns}	14.53**	2.55 ^{ns}
D	0.64 ^{ns}	0.73 ^{ns}	6.81**	14.44**	0.03 ^{ns}	0.75 ^{ns}
T × D	0.88 ^{ns}	1.58 ^{ns}	1.34 ^{ns}	2.45 ^{ns}	1.10 ^{ns}	0.54 ^{ns}
SMD	11.71	15.50	2.84	5.78	12.85	16.62
CV	11.62	15.80	15.26	21.40	10.76	13.30
General Mean	137.09	133.00	25.36	36.70	162.45	170.00

Note. ns = not significant at the $P \leq 0.05$ level; * = significant at 5% probability by F test; ** = significant at 1% probability by F test; SMD = significant minimum difference; CV = Coefficient of Variation (%).

[1] $y = 0.051x + 21.531$ ($R^2 = 85.04\%$);

[2] $y = 0.0016x^2 - 0.3775x + 50.677$ ($R^2 = 85.21\%$).

However, the work of Alves et al. (2015) uses the same cultivar of this study and obtains different results. As the rice plant response to the application of exogenous cytokinin is variable, it is possible that in the present study the plants response to the TDZ dose used was the reduction of the amount of grains per panicle, that is, it was very high and resulted in losses to the plant, differing from what occurred in the work cited. It is noteworthy that, in this study, the dose used was 1.0 g ha^{-1}, 0.1 g ha^{-1} more than the maximum dose used by Alves et al. (2015). By observing the linear behavior caused by TDZ doses in the work by Alves et al. (2015) and the effects using the fixed dose in this work, it is possible that, for the cultivar BRS Esmeralda, the maximum point for doses of TDZ with respect to these variables be between these two doses.

For the ethyl-trinexapac, in both years of cultivation, only the amount of unfilledgrains per panicle was affected by the doses of the regulator applied. In the first year, the data fitted an equation of increasing linear regression, with an increase in the quantity of unfilled grains per panicle in function of the increase in the doses of the regulator used. However, in the second year, the data fitted a quadratic regression equation with the minimum point dose at 115.40 g ha^{-1}. Silva (2009) observed that the application of growth regulator increased the number of filled, unfilled and total grains per panicle only in the second sowing season, so that the application of the regulator decreased the means of these variables. Alvarez et al. (2014) observed that spikelet fertility (ratio between filled grains and total grains) decreased linearly with increasing doses of ethyl-trinexapac.

The rice hectoliter mass was another variable not affected by any of the treatments (Table 3). Thus, the application of TDZ and the doses of ethyl-trinexapac used did not change this characteristic of the grains produced in neither years of cultivation. The means for both years of cultivation did not exceed 50.50 kg 100 L^{-1}, somewhat lower than found in other works. The application of ethyl-trinexapac doses did not affect the hectoliter mass in this study. Nascimento et al. (2009), on the other hand, showed that the hectoliter mass of the grains produced fitted a quadratic regression equation in function of the doses of ethyl-trinexapac used, so that the application of the growth regulator initially benefited hectoliter mass. What may have happened is that the reduction in plant height allowed the photoassimilates, which would be used to increase plant height, to be used for the filling of grains.

Table 3. Average values for hectoliter mass (Hect), mass of one hundred grains and grain yield of cv. BRS Esmeralda in function of the application of thidiazuron and doses of ethyl-trinexapac. Selvíria, MS (2015/16 and 2017/18)

Treatments	Hect (kg 100 L^{-1})		M 100G (g)		Grain Yield (kg ha^{-1})	
	15/16	**17/18**	**15/16**	**17/18**	**15/16**	**17/18**
Thidiazuron (T)						
Thidiazuron	50.69	48.07	2.70	2.68a	4.958	6.542
Nontreated	50.19	47.21	2.67	2.62b	4.739	6.599
Doses of Ethyl-trinexapac (D)						
0.0	51.23	47.42	2.72	2.56[1]	5.802[2]	6.550
50.0	51.10	47.69	2.69	2.62	4.813	6.843
100.0	50.48	46.49	2.68	2.70	4.826	6.614
150.0	48.95	48.95	2.66	2.71	3.950	6.273
F Test						
T	0.66 ns	0.81 ns	0.98 ns	9.75**	0.99 ns	0.04 ns
D	2.95 ns	1.12 ns	0.93 ns	14.01**	11.83**	0.76 ns
T × D	2.09 ns	0.11 ns	2.77 ns	1.91 ns	1.36 ns	0.15 ns
SMD	1.27	1.99	0.05	0.04	457.58	561.36
CV	3.42	5.68	2.72	2.07	12.84	11.62
General Mean	50.44	47.64	2.68	2.65	4,848.22	6,570.29

Note. ns = not significant at the $P \leq 0.05$ level; * = significant at 5% probability by F test ** = significant at 1% probability by F test, SMD = significant minimum difference. CV = Coefficient of Variation (%).

[1] $y = 0.0011x + 2.5681$ (R^2 = 93.37%);

[2] $y = -11.086x + 5679.7$ (R^2 = 89.41%).

Arf et al. (2012) observed effects of doses of ethyl-trinexapac on three of the four cultivars used in their work, so that only the cultivar IAC 202 was not affected. The data of the cultivars BRS Primavera and Caiapó fitted quadratic regressions in function of doses of ethyl-trinexapac, whereas for the cultivar BRS Soberana, there was a linearly decreasing fitting of data.

The weight of one hundred rice grains did not differ whether or not TDZ and doses of ethyl-trinexapac were used in the first year of cultivation. In the second year, however, the application of TDZ resulted in an increase of about 2.3% in the mass of one hundred grains in relation to the treatment without application. As for the doses of ethyl-trinexapac, the values found for this variable fitted a linear regression equation in function of doses.

Alves et al. (2015) shows that the application of TDZ affected the mass of one hundred rice grains in both cultivars analyzed in their study. For the cv. BRS Esmeralda, there was fitting to the quadratic regression, with the maximum point at the dose at 0.48 g ha^{-1}, resulting in a mass of one hundred grains of 2.98 g. For the cv. IAC 202, there was an adjustment to a positive linear regression, with an increase of 3.2% in the maximum dose in relation to the control, similar to that found in the second year of this study. However, Garé et al. (2017) observed no changes in this variable in function of doses of TDZ used in upland rice cultivar ANa 5015. It is noteworthy that the general average of such variable observed by them was higher than the one verified in this work.

As regards ethyl-trinexapac, the literature results vary. Arf et al. (2012), for example, shows that the averages of this variable adjusted to positive linear regressions in function of doses of ethyl-trinexapac used for the cultivars BRS Primavera and Caiapó, corroborating the results found in this study. However, the same study observed that plant regulator doses did not affected this variable for the cultivars BRS Soberana and IAC 202. On the other hand, Yamashita (2013) did not observe effects of the doses of the same regulator on the mass of one hundred grains of the cultivar BRS Primavera. In his work, this variable was only affected by the application time of the regulator, being impaired when the application occurred when the crop was stuffed.

Grain yield, in both years of cultivation, was not affected by the application of TDZ during crop tillering. However, for ethyl-trinexapac doses, in the first year, there were losses due to the application of the regulator. The data obtained fitted a decreasing linear regression equation. The application of TDZ basically aimed to benefit crop yield. Alves et al. (2015) observed a grain yield increase of 23.5% in cv. BRS Esmeralda and 6.5% in cv. IAC 202. However, the results obtained in this study for both years of culture were the opposite of what was expected, even using a dose slightly higher than the maximum dose used by Alves et al. (2015). On the other hand, the results found by Garé et al. (2017) and Buzo et al. (2018) corroborate the results of this study. The authors did not verify changes in upland rice yield in function of the application of thidiazuron via leaf at crop tillering.

It is emphasized that cytokinins are generally capable of extending the photosynthetic productivity of plants, promoting nutrient mobilization by forming a new source-drain relationship and stimulating cell division and stretching. The consequence of these physiological effects would be, for example, the occurrence of a larger grain filling and, consequently, an increase in the already analyzed variables. However, in this work and in two works mentioned above, such increases were not observed. This could be related to the plant's endogenous production of cytokinins (which may have been sufficient to meet its physiological needs) and the environmental conditions to which it was exposed (they were not stressful to the point of reducing the endogenous levels of cytokinins).

In relation to the ethyl-trinexapac growth regulator, Silva's (2009) work showed that its application reduced rice yields by 45% and 30% on the first and second sowing dates, respectively. Alvarez et al. (2014) observed that the rice yield fitted a quadratic regression equation in function of doses of ethyl-trinexapac. Arf et al. (2012) observed that the grain yield of the cultivar IAC 202 in function of doses of ethyl-trinexapac fitted a linear regression equation. Thus, the application of the regulator affected crop yield. However, for the cultivars BRS Primavera and Caiapó, the authors observed a fitting of data to quadratic regressions. Thus, ethyl-trinexapac, while very advantageous in reducing the problems related to crop lodging, has the disadvantage of being able to significantly reduce crop yield. This will depend on the dose used and on the state of the plant. If the plant is in a proper condition, the grain yield will only decrease when subjected to higher doses of the regulator. However, if the plant is not in optimal development conditions, the regulator may affect production even at lower doses.

This assertion can be made by observing that, in the first year of this study, the control had a mean yield of 5,802.47 kg ha^{-1}, and the crop was drastically affected by the application of the regulator. On the other hand, in the second year of cultivation, the average yield of the control was 6,550.38 kg ha^{-1}, almost 1 Mg ha^{-1} higher than the first year. No ethyl-trinexapac dose used affected crop yield in the second year. This higher grain yield from one year to the next indicates that the crop developed under quite different environmental conditions. In the second year, it was exposed to environmental conditions much more favorable for its development than in the first year. Probably because of this, we observed a difference of results regarding the effects of ethyl-trinexapac doses on crop yield.

4. Conclusions

(1) Thidiazuron reduces the number of filled grains, grains unfilled and whole grains per panicle, increases the mass of one hundred grains of rice, and does not affect the grains yield produced.

(2) Ethyl-trinexapac reduces plant height, eliminates lodging, increases the amount of coarse grains, and may affect the mass of one hundred grains and rice grain yield.

(3) The simultaneous use of both plant regulators does not result in any interaction in rice cultivation.

(4) The application of TDZ is not necessary to increase rice yield and to eliminate lodging. The lowest dose of ethyl-trinexapac (50 g ha^{-1}) is the best, as it results in fewer chances of a reduced grain yield and less costs to the producer.

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