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TRINEXAPAC-ETHYL REDUCES PLANT HEIGHT AND SEED YIELD IN FORAGE SORGHUM

ABSTRACT - Forage sorghum presents tall plants, what makes mechanical seed harvesting a difficult task. Plant hormones can reduce plant height and facilitate the harvesting. Thus, the objective of this study was to evaluate the effect of the growth regulator trinexapac-ethyl on plant height and seed yield in forage sorghum. This research was carried out at Embrapa Maize and Sorghum, in two seasons (2017 and 2018), in a randomized complete block design, four replications and three varieties (BRS Ponta Negra, 1141574 and 0947216) under application of Trinexapac-ethyl in two stages of the plant growth (V8, V12, V8 + V12). The characteristics evaluated were: plant height, seed yield and mass of 1000 seeds. The effect of the hormone was significant in both stages of growth, with a significant reduction in plant height. The hormone applied twice at growth stages V8 + V12 had a greater effect in reducing plant height. However, the hormone reduced seed yield in the three varieties, what implies the need for further studies comparing the advantage of plant height reduction and the loss in seed yield.

Keywords: *Sorghum bicolor*; sorghum seed production, plant-growth regulator.

TRINEXAPAQUE-ETÍLICO REDUZ ALTURA DE PLANTA E PRODUÇÃO DE SEMENTES EM SORGO SILAGEIRO

RESUMO - O sorgo silageiro possui plantas de porte alto, o que dificulta a colheita mecanizada em campos de produção de sementes. Assim, o objetivo deste estudo foi avaliar o efeito do regulador de crescimento trinexapaque-etílico em sorgo forrageiro, visando a redução de altura de plantas para facilitar a colheita de sementes. O trabalho foi realizado na Embrapa Milho e Sorgo, em dois anos (2017 e 2018), com delineamento de blocos casualizados, quatro repetições, três variedades (Ponta Negra, 1141574 e 0947216), e aplicação do trinexapaque-etílico em dois estádios de crescimento da planta (V8, V12, V8+V12). As características avaliadas foram: rendimento de grãos, altura de plantas e massa de 1000 sementes. Houve efeito do hormônio em ambos estádios de desenvolvimento do sorgo (V8 e V12), e o regulador de crescimento aplicado duas vezes (V8+V12) teve maior efeito na redução da altura das plantas. A interação hormônios x variedades foi significativa para altura de plantas, ou seja, cada variedade teve comportamento diferente quando aplicado o regulador de crescimento. Como característica negativa, o uso do hormônio reduziu o rendimento de sementes. Portanto o produtor de sementes precisa analisar a vantagem desta redução da altura de planta, em relação à perda de produtividade de sementes.

Palavras-chave: *Sorghum bicolor*; hormônio de crescimento, produtividade de sementes de sorgo.

The forage demand for animal feeding has significantly grown in the market, due to the increase in exports of meat and dairy products. In this sense, the use of silage for cattle feeding during the off-season is an excellent option. Maize and sorghum are the most used crops for silage purpose (Rodrigues et al., 2015). In Brazil, there are excellent forage sorghum cultivars, adapted to the tropical climate, with high dry matter yields, helping to meet the demand and balance of high quality silage.

Sorghum, in general, presents some advantages of use, linked to the reduced interval of feed supplying, during the seasonality of the pastures, due to the lesser rainfall regime of the period fall/winter. The first of them is the feed supplying when there is a poor production of other crops during the off-season. The other advantage is that sorghum presents a greater adaptability when compared to other crops, presenting a greater yielding efficiency under adverse conditions, such as under water stress and in different environments (Magalhães et al., 2007; Santos et al., 2013; Carvalho, 2017). Among the physiological mechanisms of sorghum adaptation to overcome water stress, its photosynthetic efficiency and deep root system stand out (Magalhães et al., 2014).

Silage sorghum plants have strong stalks, height of 2.5 m, with a good balance in the grain/plant ratio and high dry matter yield, which guarantees high quality forage. This type of sorghum still shows good digestibility, which reflects in animal nutrition, being an excellent

forage, used in cattle feedlots, and especially in dairy production (Rodrigues et al., 2015).

The expansion of livestock in feedlot regimen causes stockmen to pay attention to the need for silage storage, in order to feed the livestock with the necessary nutritional attributes throughout the year (Nardes, 2019). Thus, silage is a forage storage technique that allows for the conservation of good quality feed (Paula, 2016). The ensiling process is done by crushing the green mass of the plant, making the storage in the silo, compaction, sealing and ingestion by animal's easier, increasing palatability (Senger et al., 2005; Dunière et al., 2013).

For the production and multiplication of seeds of forage cultivars, the tall plant makes the harvesting process difficult, which only aims at cutting the panicle, where the seeds lie. As the seed approaches physiological maturity, the panicle becomes heavier; the plant stalks dry and thus, the plants become more susceptible to lodging and/or breakage (Rodrigues et al., 2015). When working with hybrids, this problem is overcome by using two short lines, but with *Dw* genes that complement each other, generating a tall plant hybrid. However, when using varieties, this option does not exist.

The combine machine used in forage sorghum seed producing-fields is the same as that of the grain sorghum, which presents plants with reduced size (150 cm), with combines working in a lower range. There is a considerable loss of panicles that fall outside the combine platform, when it is necessary to harvest forage sorghum

plants. An alternative would be to raise the reel of the combine, which would reduce panicle losses. However, this adjustment of the bar at each harvest over time generates attrition on the elevators, ending in an early damage on the combine machine.

Therefore, an alternative to improve the efficiency of mechanized harvesting of forage sorghum cultivars is the use of plant growth regulators applied to leaf area of the plants in order to reduce their height. However, according to Rademacher (2000), the use of hormones to reduce plant height must be well regulated, to avoid a loss in yield of both seed and green mass.

There is little information about the use of growth regulators in sorghum plants, mainly related to the timing of application. Therefore, the aim of this study was to evaluate the effect of plant growth regulator (trinexapac-ethyl) on three forage sorghum cultivars, aiming to reduce plant height to help seed harvesting in production fields.

Material and Methods

The experiment was carried out in two agricultural years, 2017/2018 and 2018/2019 harvests, at the Embrapa Maize and Sorghum experimental station, located in Sete Lagoas, MG, Brazil, at latitude 19°27'17" S, longitude 44°14'48" W and 761 m of altitude. The experimental design used was in randomized blocks, with four replications, where three varieties of forage sorghum (BRS Ponta Negra,

1141574 and 0947216) were evaluated, either with or without application of the growth regulator (trinexapac-ethyl). BRS Ponta Negra is a commercial variety used for silage production in the Northeast and for cover crop in the Midwest, due to its poor nematode reproduction factor. The other two varieties are experimental; they have been participating in competition trials, with the possibility of being released because their better resistance to diseases.

The study consisted of four treatments. One without hormone application. The second and third treatments consisted in the application of the hormone when the plants were at growth stages V8 and V12, respectively. The fourth treatment consisted of two hormone applications, one at V8 and the other at V12 stages (V8+V12). The growth regulator was applied to the plants with the aid of a backpack spray with pressurized CO₂, with constant pressure and flow. In the first year, a dose of 250 g ha⁻¹ of active ingredient was applied and in the second year the dose was increased to 250 g a.i. ha⁻¹, considering the volume of spray of 200 g a.i. ha⁻¹ in both years, aiming at the difference of times and the effect of the hormone on the plants.

The plots consisted of four rows of five meters in length, the two central rows being considered as the useful area, with inter-row spacing of 0.7 m. For the planting fertilization, 350 kg ha⁻¹ of the formula 8-28-16 (NPK) were applied, and 20 days after sowing 200 kg ha⁻¹ of urea at topdressing fertilization were applied. Also, supplementary irrigation was used in order

to avoid water stress.

Sowing was performed manually, using 20 seeds m^{-1} at a depth of 3 cm. At 15 days after sowing, thinning was carried out, leaving 10 plants m^{-1} to obtain a final stand of 140,000 plants ha^{-1} . The crop management consisted of two manual weeding and insecticide applications to control the fall armyworm.

The characteristics evaluated were: plant height, measured in cm, between the soil and the apex of the panicle; seed yield, measuring the grain mass, being corrected to 13% moisture and later extrapolated to $kg\ ha^{-1}$; and mass of a thousand grains, where a thousand grains were randomly chosen and the mass determined with the aid of an analytical balance.

The data were subjected to analysis of variance. When significant, the values were compared by using Tukey's test ($p \leq 0.05$). The analyses were performed with the help of the Sisvar software version 5.3 (Ferreira, 2011).

Results and Discussion

There was a significant effect for the source of variation years for the characteristics plant height and a thousand-seed mass. This effect is related to the dose of the hormone that was higher in the second year. The source of variation hormones was significant for seed yield and plant height, indicating the influence of the hormone on these characteristics. The varieties performed differently for the three evaluated characteristics (Table 1).

The interaction years x hormones was significant for seed yield and plant height, showing that the hormone action was different between the years of evaluation, which was expected, since there was an increase in the dose of 200 g a.i. ha^{-1} to 250 g a.i. ha^{-1} from the first to the second year of planting.

On the other hand, the interaction years x varieties (Y x V) was not significant for all the characteristics, showing that the varieties performed similarly in the two years. The interaction between varieties and hormone (H x V) was significant for plant height and a thousand seed mass, showing that the hormone effect may be different for each variety. The triple interaction Y x H x V was non-significant, which indicates similar behavior of application times and varieties in the two years of the study.

The coefficient of variation (CV%) for seed yield showed greater dispersion in relation to the other characteristics evaluated, but at acceptable levels to consider good experimental precision.

In Figure 1, the means of the plant heights of the four treatments studied (no-hormone, hormone applied in stages V8, V12 and in V8 + V12) are observed. It is verified that plant height was affected by the application of the hormone as soon as in V8 stage, the reduction being even more significant when applied in V8 + V12. In this case, there was a 40% reduction in plant height in the two applications (V8 + V12) of trinexapac-ethyl compared to control without application.

Table 1. Summary of the joint analysis for seed yield, plant height and 1,000 grain mass for three forage sorghum varieties submitted to trinexapac-ethyl hormone application.

SV	FD	MS		
		Seed Yield (kg ha ⁻¹)	Plant height (cm)	1,000 grain mass (g)
Year (Y)	1	996744.99 ^{ns}	76049.99**	150.00**
Hormone (H)	3	11255716.98**	50224.98**	0.25 ^{ns}
Varieties (V)	2	23231977.98**	56285.98**	1145.00**
Y x H	3	2187227.99**	8117.98**	1.53 ^{ns}
Y x V	2	1310605.98 ^{ns}	694.98 ^{ns}	1.97 ^{ns}
H x V	6	711760.99 ^{ns}	1011.00**	12.86**
Y x H x V	6	678231.99 ^{ns}	385.97 ^{ns}	2.75 ^{ns}
Error	66	432295.99	3851.99	3.25
CV (%)	-	20.75	9.26	6.79
Mean	-	3168.00	212.35	26.54

** and ns: Significant at 1% and non- significant, respectively.

CV: Coefficient of variation

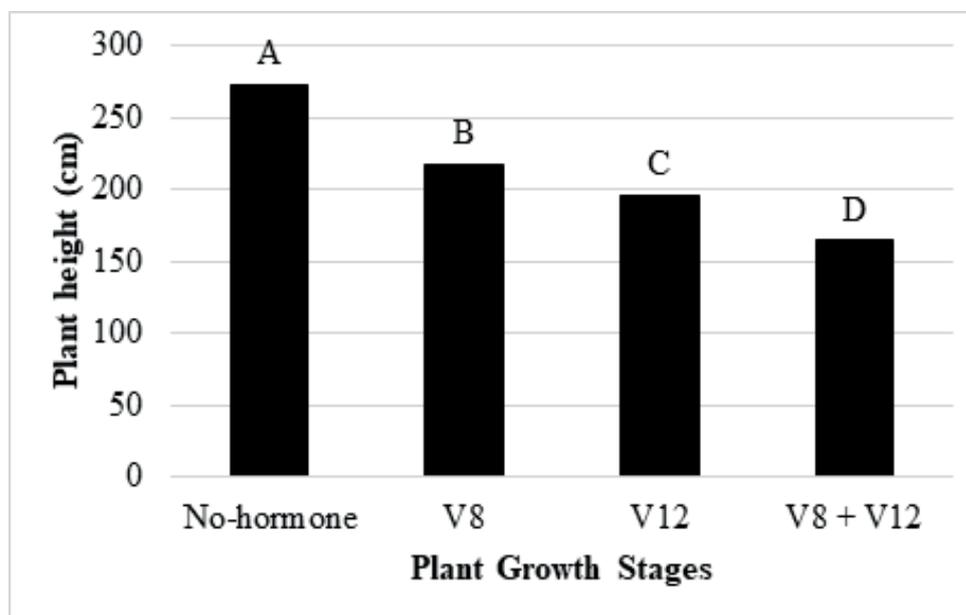


Figure 1. Means of plant height (cm) of sorghum varieties submitted to the application of trinexapac-ethyl hormone, at two plant growth stages. Different letters on the bars indicate a significant difference by the Tukey test ($p \leq 0.05$).

A similar behavior was observed by May et al. (2013), when they used this same hormone in sweet sorghum plants, conducted in a greenhouse, where they noted that the height of the plants was more influenced by higher doses. In this case, a greater reduction was observed in the size of the plants that were submitted to two applications, carried out at stages V6 + V10. These results must be related to the greater amount of the product that these plants received. Thus, a greater effect can be obtained in inhibiting gibberellin, capable of increasing the metabolic activity or the effectiveness of abscisic acid, which thus inhibits the cellular elongation of the internodes (Korol & Klein, 2002; Ervin et al., 2002; Nakayama et al., 1990).

The general average plant height of the

varieties without a hormone application was 273 cm, which is a significant height for forage sorghum cultivars, whose main characteristic is the large content of dry mass and nutritive value, which are directly related to the height of the plants, proportion of leaves, stalks and panicles (Molina et al., 2000).

When comparing the mean of each variety, BRS Ponta Negra was the least affected by the action of the growth regulator, when compared to the varieties 1141574 and 0947216 (Figure 2). In varieties 1141574 and 0948216, the hormone was more efficient, resulting in a reduction up to 131 cm between treatments without a hormone application (control) and V8+V12 application, which represents a 49% reduction in plant height.

When using only one application of

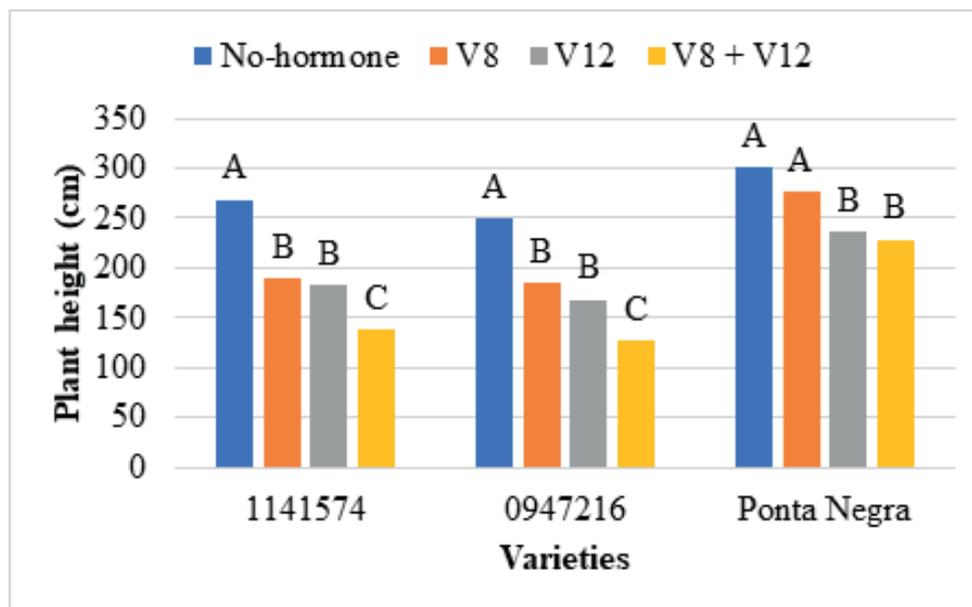


Figure 2. Plant height means (cm) of three varieties of sorghum submitted to application of trinexapacetyl, at two plant growth stages. Different letters on the bars, in each genotype, indicate a significant difference by the Tukey test ($p \leq 0.05$).

the hormone, the application in V12 was more efficient than when applied in V8, so when it is impossible to do two applications, we must choose a later stage to perform the application (Figure 1). Apparently, if the hormone is applied too early, it loses its effect over time and the plant starts to grow again. In the variety 0947216, there was a 59 cm reduction in plant height when the hormone was applied at V8+V12, compared to application only in the V8 stage (Figure 2). The variety 1141574 showed a reduction of 51 cm in stage V8 + V12 compared to V8. The variety BRS Ponta Negra showed a final reduction of 47 cm after the V8 + V12 application in relation to the V8 stage. The plant height reached by the varieties 1141574 and 0947216, when applying the hormone in V8 + V12, is within the ideal for mechanized harvesting, being similar to grain sorghum, which is normally around 140 cm. The variety BRS Ponta Negra even with the two doses applied, showed a plant height of 229 cm, still high for better harvester performance, but better anyway than the initial height without a hormone application.

Fagherazzi (2015) working on maize hybrids showed results in relation to the times of application of the hormone trinexapac-ethyl in which the plant height started to be affected from the V6 phenological stage. The application of trinexapac-ethyl in plants in the seven-leaf phenological stage reduced plant height more than when compared to the five-leaf stage.

In figure 3, the means for seed yield of the four varieties are presented. The hormone

significantly reduced seed yield. When applied once, at V8 or V12 stages, it reduced seed yield around 24% compared to the treatment with no-hormone. Moreover, when applied twice, at V8 and V12, the hormone was more unfavorable with 41% of seed reduction. Fagherazzi (2015), evaluating maize genotypes using the growth regulator trinexapac-ethyl, found a reduction in the biological yield of the crop with sequential applications from stages V2 to V7, for the single hybrid P30F53 and the variety SCS 154 Fortuna.

The individual results of each variety were analyzed according to the means of the two-year analyses (Figure 4). Seed yield reduced even in treatments with only one application in stage V8. The reduction in yield was greater when the varieties received two applications in stages V8+V12, with the exception of the variety BRS Ponta Negra, which did not present any significant difference between the applications in stages V8, V12 and V8 + V12. These results showed that the variety 0947216 was the most affected by the hormone, with a reduction of 1,967 kg ha⁻¹ of grains, which represents a 58% yield drop, when compared to the control, with no-hormone. The variety BRS Ponta Negra was less affected by the application of the growth regulator, presenting a 26% reduction in yield, compared to control and application in V8+V12.

In rice, the hormone trinexapac-ethyl presented a negative effect on grain yield and quality (Silva, 2009). According to Linzmeyer-Júnior (2006), this condition of reduced yield with the use of trinexapac-ethyl may be related

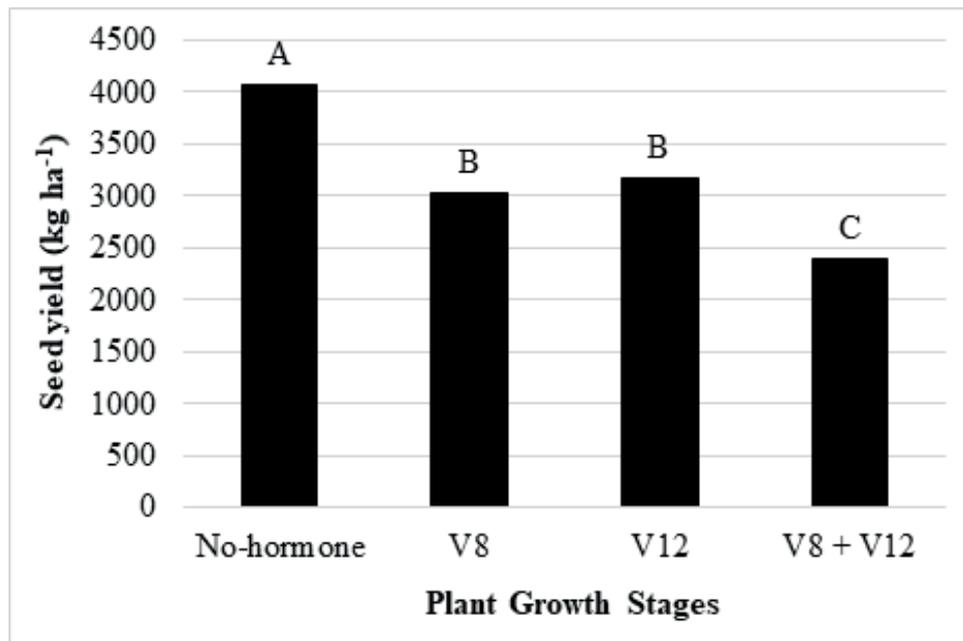


Figure 3. Seed yield (kg ha⁻¹) of sorghum varieties submitted to the application of application trinexapac-ethyl, at two plant growth stages. Different letters on the bars indicate a significant difference by the Tukey test ($p \leq 0.05$).

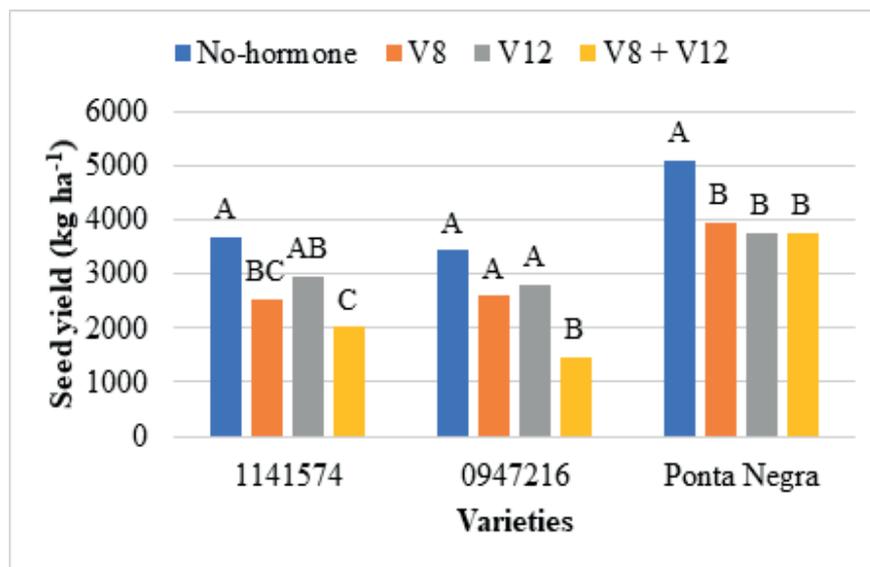


Figure 4. Seed yield (kg ha⁻¹) of three forage sorghum varieties submitted to the application of trinexapac-ethyl, at two plant growth stages. Different letters on the bars, in each genotype, indicate a significant difference by the Tukey test ($p \leq 0.05$).

to the use of doses greater than 150 g ha⁻¹ of the active ingredient of the product, and that this effect is dependent on crop.

Regarding the means of the three varieties, the mass of one thousand grains of forage sorghum

submitted to the application of trinexapac-ethyl did not present any significant difference (Figure 5). Similar results obtained by Alvarez et al. (2007) showed that the mass of one-thousand rice grains also resulted in a non-significant

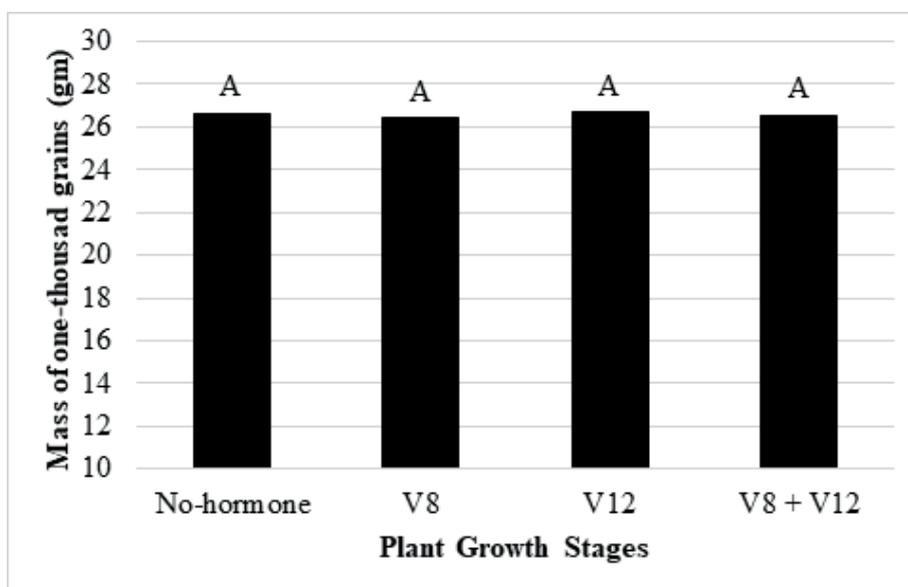


Figure 5. Mass of one-thousand grains of sorghum submitted to trinexapac-ethyl, at two plant growth stages. Different letters on the bars indicate a significant difference by the Tukey test ($p \leq 0.05$).

difference between treatments.

In the analysis of each variety, genotype 0947216 showed a small reduction in the mass of a thousand grains, comparing the control treatment and the V8+V12 application. The varieties 11414574 and BRS Ponta Negra, on the other hand, resulted in a 5% increase in the size of their grains, in relation to the control without application (Figure 6). These data corroborate with studies in maize hybrids, where the variable mass of a thousand grains was not influenced by the applications of the growth regulator

trinexapac-ethyl either, according to results reported by Fagherazzi (2015). A similar result was observed in wheat cultivars (Penckowski et al., 2010).

According to the joint analysis of the two years, 2017 and 2018, in the first application, at stage V8, a significant reduction in plant height was observed. The hormone was most effective for plant height reduction when applied in the stages V12 and V8+V12, considering the joint average of the three varieties. The varieties 0947216 and 1141574 showed greater

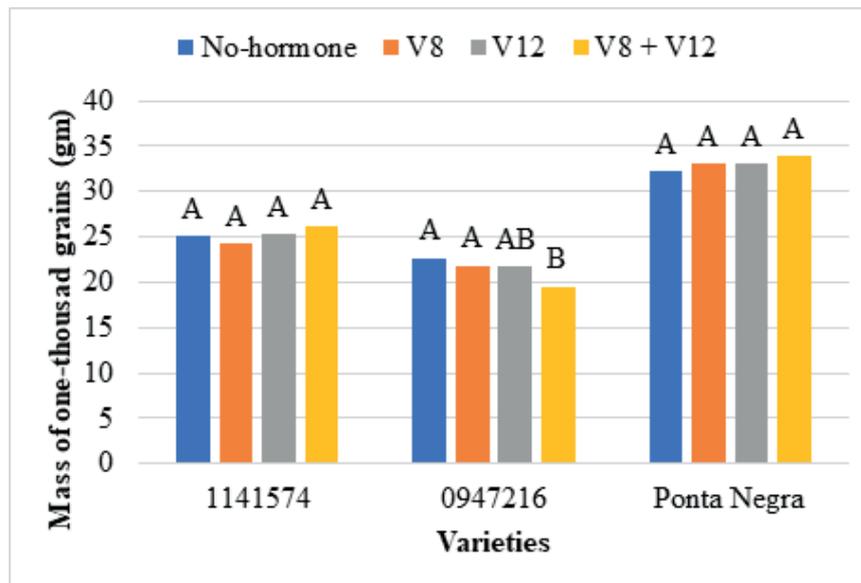


Figure 6. Mass of one-thousand grain of sorghum varieties submitted to trinexapac-ethyl, at two growth stages. Different letters on the bars, in each genotype indicate a significant difference by the Tukey test ($p \leq 0.05$).

sensitivity to the hormone than the variety BRS Ponta Negra as far as plant height is concerned.

The growth regulator significantly reduced seed yield, according to the results obtained in the joint analysis, of the three varieties. The 0947216 and 1141574 varieties, which showed more sensitivity to hormone application, a greater drop in yield was recorded, but without a significant influence on grain size. However, the negative effects on the yield must be considered, comparing costs of harvesting seeds from taller plants. In other words, it is necessary to measure whether the harvest costs outweigh the losses, in terms of yield. Otherwise, the use of the hormone must be more rigorously evaluated, and even disregarded.

Similar results was observed by Alvarez et al. (2007), in an analysis of the rice crop using the growth regulator trinexapac-ethyl, which showed a reduction in grain yield and also interfered in the number of panicles and spikelets after the application of the hormone. The application of the growth regulator did not influence the grain mass, which may indicate that the reduction in yield occurred due to the reduction in the number of grains.

Studies of the effect of trinexapac-ethyl on both the vigor and germination of sorghum seeds do not exist, and even in other crops are scarce. This hormone is mostly used in sugarcane to reduce internodes and increase the number of buds in seedling multiplication, and also in

grasses seeking to shorten the plants and reduce lodging. In red clover, in doses of up to 0.42 kg of active ingredient per hectare, no reduction in seed germination occurred (Kirk et al., 2016). In ryegrass, the application of trinexapac-ethyl at inflorescence emergence stage did not reduce seed vigor and germination, whereas in the early flowering phase it reduced seed vigor and germination by 14% and 10%, respectively (Schaeffer, 2020). It seems that the effect of the hormone on seed production and quality is dependent on the crop, dose and stage of application of the product. Studies about the effect of trinexapac-ethyl on the quality of sorghum seeds are necessary to support the results found in this work, and to help seed companies in making decision.

Conclusions

The application of the growth regulator trinexapac-ethyl significantly reduces the height of forage sorghum plants.

The hormone is most efficient when applied twice in stages V8+V12.

The hormone negatively affected seed yield, which must be carefully reviewed in order to make the correct decisions regarding the use or not of the hormone, although its effect may vary from one variety to another.

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