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Growth retardants in dry bean plants: impacts on the architecture, photoassimilate partition, and their consequences on the yield

Redutores de crescimento em feijoeiros: impactos sobre a arquitetura, partição de assimilados e suas consequências sobre a produção

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Abstract. The objective of this study was to evaluate the effects of three growth retardants on the development and yield of dry bean plants. The treatments were control (water), maleic hydrazide (0.09 g a.i. L^{-1}), ethyl-trinexapac (0.5 g a.i. L^{-1}) and propiconazole (0.125 g a.i. L^{-1}). Maleic hydrazide decreased the plant growth rate, resulting in the height reduction (46%). It also inhibited the twining shoot development, thus controlling the vigor excess of this genotype which has indeterminate growth. On the other hand, plants which were treated with ethyl-trinexapac and propiconazole showed the higher heights (from 25 to 52%, respectively), indicating that both compounds provide the plant growth. These compounds also increased the number of pods (48 to 52%) and grains (47 to 102%), when compared to the control. However, ethyl-trinexapac and maleic hydrazide decreased 50-grain dry mass (41 to 52%), indicating changes in the photoassimilate partition among plant structures. This change was evidenced by the correlation coefficient of the biomass allocated between the shoots and grains, which was inversely proportional (r=-60.57) and highly significant (p=0.0002). It is concluded that maleic hydrazide is an efficient growth inhibitor of dry bean plants. Propiconazole and ethyl-trinexapac provide the plant growth, and also improve the main yield components. However, ethyl-trinexapac and maleic hydrazide decrease grain biomass.

Keywords: Ethyl-trinexapac, maleic hydrazide, *Phaseolus vulgaris*, plant growth regulators, propiconazole

Resumo. O objetivo do presente trabalho foi avaliar os efeitos de três redutores de crescimento sobre o desenvolvimento e produtividade de feijoeiro. Os tratamentos foram controle (água), hidrazida maleica (0,09 g i.a. L^{-1}), etil-trinexapac (0,5 g i.a. L^{-1}) e propiconazol (0,125 g i.a. L^{-1}). A hidrazida maleica diminuiu a taxa de crescimento das plantas, resultando na redução da altura (46%). Ela também inibiu o desenvolvimento do caule volúvel, controlando assim o excesso de vigor deste genótipo que possui um hábito de crescimento indeterminado. Por outro lado, plantas tratadas com etil-trinexapac e propiconazol apresentaram as maiores alturas (25 a 52%, respectivamente), indicando que ambos compostos promovem o crescimento vegetal. Eles também aumentaram o número de vagens (48 a 52%) e de grãos (47 a 102%), quando comparados ao controle. Entretanto, etil-trinexapac e hidrazida maleica diminuíram a massa seca de 50 grãos (41 a 52%), indicando mudanças na partição de fotoassimilados entre as estruturas da planta. Esta alteração foi evidenciada pelo coeficiente de correlação da biomassa distribuída entre a parte aérea e grãos, que foi inversamente proporcional (r=-60,57) e altamente significativo (p=0,0002). Conclui-se que a hidrazida maleica é um eficiente inibidor do crescimento de feijoeiro. Propiconazol e o etil-trinexapac promovem o crescimento vegetal e melhoram os principais componentes de produção. Entretanto, o etil-trinexapac e hidrazida maleica diminuem a biomassa alocada em grãos.

Palavras-chave: Etil-trinexapac, hidrazida maleica, *Phaseolus vulgaris*, propiconazol, reguladores de crescimento vegetal

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The dry bean (*Phaseolus vulgaris* L.) is the most important food legume consumed worldwide, principally due to its nutritional properties such as the high content of proteins, fibers, vitamins and, carbohydrates (Kluthcouski et al., 2009). The dry bean is also a economically relevant crop for developing countries, especially for Brazil and India, which are the largest producers in the world (Faostat 2012).

The lodging is one of the factors which may limit the bean yield, impair the grain quality and reduce the mechanical harvesting efficiency (Silva et al., 2008). However, the plant growth regulators can be used to improve the crop performance, making the plant architecture more adapted and efficient in order to use environmental resources and inputs to support the high-yielding agronomic traits (Souza et al., 2010).

The plant growth regulators are synthetic compounds that act as chemical signals, controlling the plant development. They normally bind to receptors in the plant, triggering a series of cellular changes, which may affect the initiation or modification of tissues and organs (Taiz & Zeiger, 2010). Among the plant growth regulators, there are the growth retardants that can affect several plant characteristics, decreasing the stem elongation and leaf area, and increasing the chlorophyll content, leaves thickness, and root growth (Davies, 1995; Fletcher et al., 2000; Rademacher & Brahm, 2012).

In the current production system, smaller plants which have more balanced architecture and are able to support large number of pods and grains, until the harvest, are desirable, justifying the use of growth retardants. However, the mode of action of growth retardants is variable; and hence its effects on the plant growth is also diverse. The maleic hydrazide avoids cell division in the apical meristem of plants; on the other hand, ethyl-trinexapac and propiconazole inhibit the biosynthesis of gibberellins, reducing the unwanted shoot longitudinal growth, but not the grain yield (Davies, 1995; Fletcher et al., 2000; Rademacher & Brahm, 2012). The objective of this study was to evaluate the effects of three plant growth retardants on the development and yield of dry bean plants cv. Carioca.

The experiment was carried out under environmental conditions, at ‘‘Luiz de Queiroz’’ College of Agriculture in Piracicaba, SP, Brazil, (22º 42’ S and 47º 38’ W) from March to June 2011. However, the plants were irrigated as needed to avoid water stress. Dry bean seeds cv. Carioca were placed in plastic containers (10 dm^3) which were filled with a mixture of clay, silt and sand (2:1:1), respectively. The fertilizer [NPK (4:14:8)] was applied at substrate, following the recommendations for this crop. Ten days after planting (DAP), a homogenous adjustment was made to ensure that only two seedlings remained in each pot. The experimental design was completely randomized with four treatments and eight replicates. The treatments were: control (water), maleic hydrazide (0.09 g a.i. L^{-1}), ethyl- trinexapac (0.5 g a.i. L^{-1}) and propiconazole (0.125 g a.i. L^{-1}), which were applied twice through foliar sprays, 15 and 22 DAP. These doses and times of application were selected through tests which were previously carried out.

The plant height was provided by distance between stem base and insertion of the last leaf in upper portion, which have been evaluated weekly, from 15 to 36 DAP (time corresponding from 0 to 21 days after foliar spray). This evaluation were made when plants were in vegetative stage, and it were carried out until the beginning of flowering because at this stage the vegetative development may be affected by onset of reproductive phase due to changes in photoassimilate partition. To obtain the twining shoot length, the distance between the last leaf of upper portion and the twining shoot apex was measured 27 DAP, in order to avoid interferences in plant development due to change of vegetative to reproductive stage. Both parameters were obtained as the arithmetic mean of the values found in the two plants of each pot. The harvest was done 103 DAP, after the pods were placed in paper bags and taken to an oven for 72 h at 60 °C, to obtain the dry mass and number of pods and grains. The 50-grain dry mass, the number of grains per pod, and the shoot fresh mass were also calculated.

The data were subjected to analysis of variance (ANOVA) at 5% significance level, through the SAS® statistical software (SAS Institute, 2006). The repeated measures analysis was used to analyze the effect of treatments on the plant height along the time. The Tukey test was used to estimate the least significant range among means (p<0.05), and the regression analysis was performed to evaluate the effect of each growth retardant during such time. The shoot fresh mass, and dry mass and

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number of pods and grains were changed into $log_{10}(x)$ and heigth data to 1/x. These transformations were made to be according to the statistical assumptions to perform the ANOVA. After analysis, the data were converted back to the original scale, to facilitate comparison of results among treatments. Furthermore, in order to obtain more information about photoassimilate partition, the Pearson's correlation analysis was performed to know the type and degree of relationship between the shoot fresh mass and 50-grain dry mass.

The plant growth rate was drastically reduced by maleic hydrazide, even 20 days after spraying, showing the high efficiency of this compound regarding the growth inhibition of the dry bean plants (Figure 1).

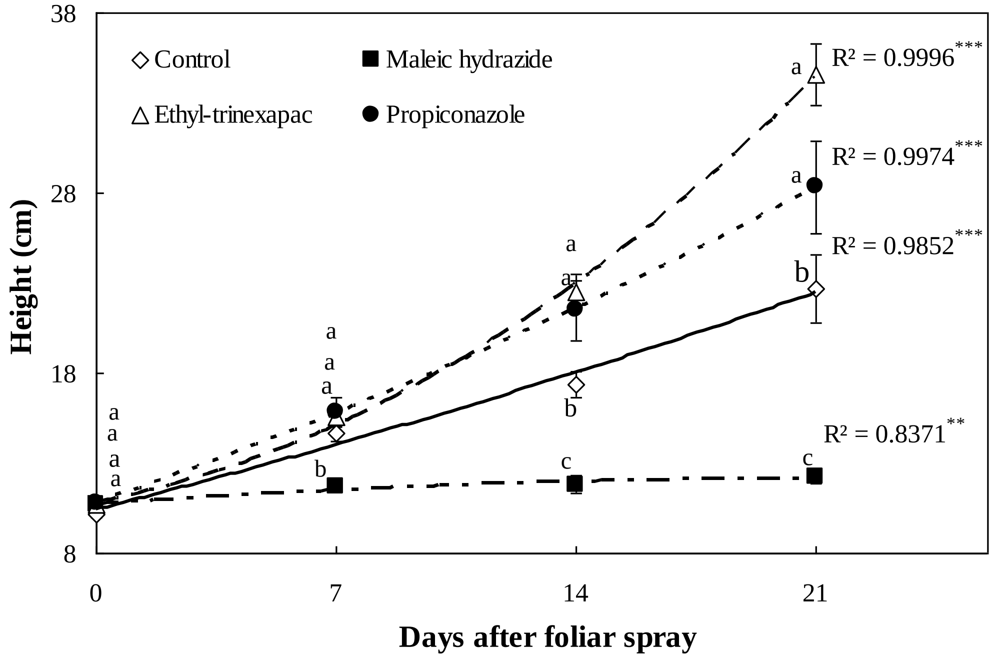

Figure 1. Growth retardant effects on the height of dry bean plants cv. Carioca throughout the experimental period. Values are the means of 8 replications ± standard error. Same letter do not differ by Tukey test at 5% among treatments, within each evaluation period (days after foliar spray). Significance: *** p <0.001, **p<0.01.

This result is due to the ability of maleic hydrazide in preventing cell division in meristematic regions (Davies, 1995; Jabee et al., 2008). On the other hand, plants treated with propiconazole and ethyl-trinexapac showed significantly higher than control at the final evaluation (an increase of 25% and 52%, respectively), indicating that these compounds provide the growth of dry bean plants. This result is different from numerous reports in the literature, claiming that ones act as growth retardants (Linzmeyer Junior et al., 2008; Souza et al., 2010; Rademacher & Brahm, 2012), which allows us to affirm that the effects on bean plants are influenced by types and doses of growth retardants.

Only plants treated with maleic hydrazide had a twining shoot inhibition, which showed a 44.04 cm difference from the control (Table 1). The twining shoot reduction is very important because it does not set much fruit, although it produces flowers. Therefore, its elimination is one way to control the vigor excess of genotypes which has an indeterminate growth, allowing the photoassimilates allocation to other producer organs, reflecting in the increased yield.

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Table 1. Growth retardant effects on the twining shoot length of dry bean plants cv. Carioca.

Treatments	Twining shoot (cm)			
Control	44.04	±	4.80	a
Maleic hidrazyde	0.00	±	0.00[1]	
Ethyl-trinexapac	52.23	±	2.58	a
Propiconazole	50.03	±	4.83	a

Values are the means of 8 replications ± standard error. Means followed by same letter do not differ by Tukey test at 5% of probability. [1]Data not included in the statistical analysis (null variance).

However, maleic hydrazide did not affect the number of pods and grains, when compared to the control. Only propiconazole increased the number of pods and seeds per pod, thus resulting in significant enhance of grain yield per plant (2.02 fold higher than the control). Despite bean plants treated with ethyl-trinexapac also showed an increase in the number of pods (51%), this growth regulator did not enhance significantly the grain yield when compared to control, even showing an increase of 47% in the number of grains, which is agronomic and commercially important to dry bean producers (Figure 2).

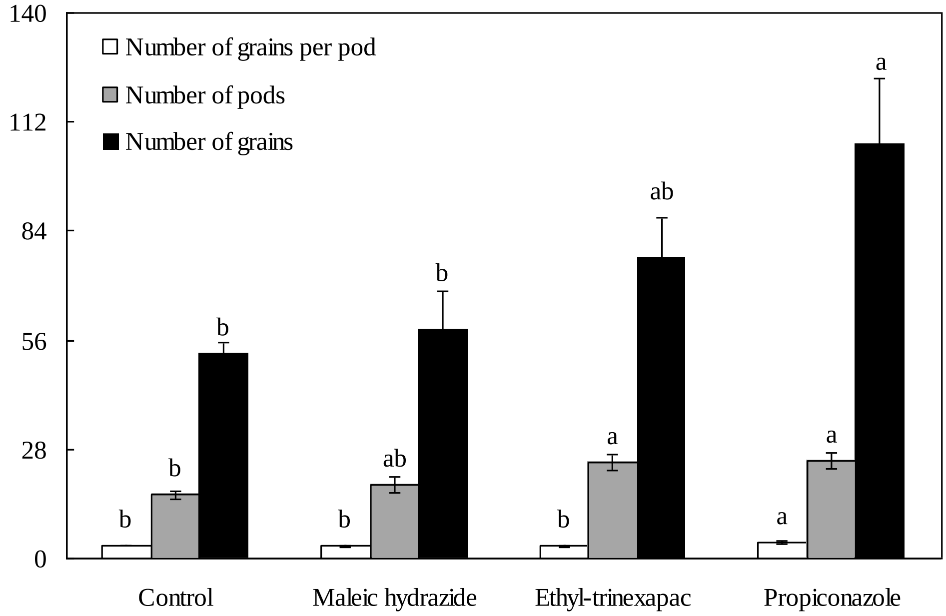

Figure 2. Growth retardant effects on the number of pods, grains and grains per pod of dry bean plants cv. Carioca. Values are the means of 8 replications ± standard error. Means followed by same letter do not differ by Tukey test at 5% of probability.

The grain yield is a parameter strongly correlated with the number of pods per plant, which depends on the number of sites for fruiting. The highest bean plants, as those treated with ethyl-trinexapac and propiconazole, probably have a higher number of fruiting sites, therefore enhancing the production of pods and grains (Souza et al., 2010).

The grain dry mass was higher in plants treated with propiconazole than the control (increase of 90%) and did not differ statistically among plants treated with ethyl-trinexapac and control. However, maleic hydrazide reduced the grain dry mass, although the number of grains were statistically similar between this treatment and control, indicating that there are changes in the grain biomass allocation (Figure 3).

This result is corroborated by the decrease of 50-grain dry mass in plants treated with maleic hydrazide, which probably interferes in protein

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biosynthesis (Appleton et al., 1981), restricting the amount of seed protein that directly represents 24 to 30% of the dry bean grains (Kluthcouski et al., 2009). Plants treated with ethyl-trinexapac also showed significant reduction of 50-grain dry mass (39%), indicating changes in the photoassimilate partition, which is probably due to alterations in the nitrogen allocation that is increased in vegetative structures and decreased in reproductive structures (Alvarez et al., 2007).

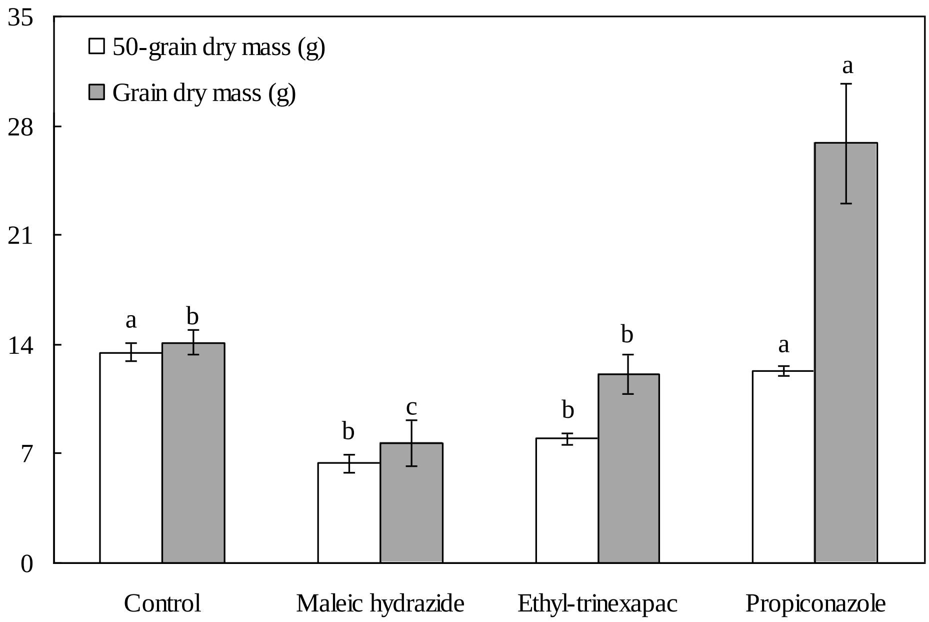

Figure 3. Growth retardant effects on grains and 50-grain dry mass of dry bean plants cv. Carioca. Values are the means of 8 replications ± standard error. Means followed by same letter do not differ by Tukey test at 5% of probability.

The changes of photoassimilate partition in plants treated with maleic hydrazide and ethyl-trinexapac become even more evident when biomass distribution among vegetative and reproductive structures is analyzed (Table 2 and Figure 3).

Table 2. Growth retardant effects on the shoot fresh mass of dry bean plants cv. Carioca.

Treatments	Shoot fresh mass (g)			
Control	21.80	±	1.51	b
Maleic hidrazyde	55.92	±	10.99	a
Ethyl-trinexapac	66.02	±	9.19	a
Propiconazole	44.91	±	5.97	a

Values are the means of 8 replications ± standard error. Means followed by same letter do not differ by Tukey test at 5% of probability.

The increase of biomass in vegetative structures (shoot fresh mass) occurs simultaneously in the reduction of the grain biomass (best represented by 50-grain dry mass). The correlation coefficient between these variables is inversely proportional (r= -60.57) and highly significant (p=0.0002), which indicates that photoassimilate partition among plant structures is changed by the use of this compounds.

It is concluded that maleic hydrazide 0.09 g a.i. L^{-1} is an effective growth inhibitor of dry bean plants cv. Carioca, because it changes the plant achitecture through height reduction and twining shoot inhibition. This growth regulator does not

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modify the number of pods, grains and seeds per pod when compared to control. However, it affects negatively the grain biomass. Propiconazole 0.125 g a.i. L^{-1} provides the growth of dry bean plants cv. Carioca. It also increases the number of pods per plant and grains per pod; therefore increasing significantly the yield. Ethyl-trinexapac 0.5 g a.i. L^{-1} provides the growth of bean plants cv. Carioca and increases the number of pods per plant. However, this compound causes a reduction of the grain biomass.

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