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Glyphosate, trinexapac-ethyl, and mepiquat chloride on the productive performance of bush snap beans

Glifosato, trinexapaque-etílico e cloreto de mepiquate no desempenho produtivo de feijão-vagem de crescimento determinado

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Abstract

Studies aimed at improving production and yield of bush snap beans are desirable; the results may provide growers with new techniques to improve profitability. In the literature, there are few reports on the productive performance of vegetables subjected to doses of glyphosate and plant regulators. Thus, this study aimed to evaluate the effect of glyphosate, trinexapac-ethyl, and mepiquat chloride doses on the production components and yield of bush snap beans. We tested various doses: a) glyphosate: 0.0; 18.0; 36.0; 72.0; and 144.0 g acid equivalent (ae) ha^{-1}; b) trinexapac-ethyl: 0.0; 62.5; 125.0; 250.0; and 500.0 g ae ha^{-1}; and c) mepiquat chloride: 0.0; 25.0; 50.0; 75.0; and 100.0 g ae ha^{-1}. The experimental design was completely randomized, with four replications per treatment. We evaluated plant height, stem diameter, number and mass of pods per plant, mass, length, and diameter of pod, and yield. The analysis of variance was conducted by applying the F test, and the doses were submitted to regression analysis ($p < 0.05$). Each active ingredient was considered separately. Productive performance was favored by using doses up to 16.0 g ae ha^{-1} of glyphosate, showing increased pod mass per plant and yield. As trinexapac-ethyl doses increased, the number of pods per plant decreased but mean pod mass increased. Doses of mepiquat chloride up to 59.5 g ae ha^{-1} increased mean pod mass. Finally, pod yield was not influenced by trinexapac-ethyl and mepiquat chloride.

Key words: Herbicide. *Phaseolus vulgaris.* Pod production. Plant growth regulators.

Resumo

Estudos que visem melhorias nos componentes de produção e no rendimento do feijão-vagem determinado são desejáveis, de modo que a sua utilização ofereça maior rentabilidade para o horticultor. Na literatura, são escassos os relatos sobre o desempenho produtivo de hortaliças submetidas a doses de glifosato e de reguladores vegetais. Deste modo, objetivou-se avaliar o efeito de doses de glifosato, trinexapaque-etílico e cloreto de mepiquate sobre os componentes de produção e rendimento do feijão-vagem de crescimento determinado. Foram testadas as seguintes doses: a) ácido glifosato: 0,0; 18,0; 36,0; 72,0 e 144,0 g e.a ha^{-1}; b) trinexapaque-etílico: 0,0; 62,5; 125,0; 250,0 e 500,0 g e.a ha^{-1}; e c) cloreto de mepiquate: 0,0; 25,0; 50,0; 75,0 e 100,0 g e.a ha^{-1}. O delineamento experimental foi o inteiramente casualizado, com quatro repetições por tratamento. Foram avaliadas as características altura de planta, diâmetro da haste, número e massa de vagens por planta, massa, comprimento e diâmetro de vagem, e rendimento de vagens. A análise de variância foi conduzida aplicando-se o teste F, e as doses submetidas

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à análise de regressão ($p < 0,05$), separadamente para cada ingrediente ativo. O desempenho produtivo é favorecido com a utilização de doses de até 16,0 g e.a ha^{-1} de ácido glifosato, em função do incremento na massa de vagens por planta e no rendimento de vagens. O incremento das doses de trinexapaque-etílico diminui o número de vagens por planta, e aumenta a massa média de vagem. Doses de cloreto de mepiquate de até 59,5 g i.a ha^{-1} incrementam a massa média de vagem. O rendimento de vagens não é influenciado com o uso de trinexapaque-etílico e cloreto de mepiquate.
Palavras-chave: Herbicida. *Phaseolus vulgaris*. Produção de vagens. Reguladores vegetais.

Introduction

Bush snap beans (*Phaseolus vulgaris* L.) are distinct from dry beans; their pods are harvested while immature and consumed with little or no processing (FURLAN et al., 2016). It is an important part of olericulture for family farming in Brazil (ABCSEM, 2011), which generates about 170 million reais for producers, due to the commercialization of approximately 50 thousand tons of pods from cultivars of determinate and indeterminate growth (CONAB, 2015).

Some advantages are attributed to determinate genotypes, such as those that do not require staking and with a shorter growing cycle, allowing a greater number of crop cycles per year. When flowering and production is concentrated over a short period, it facilitates practices such as the application of phytosanitary products and allows for a single harvest (MOREIRA et al., 2009). In contrast, indeterminate genotypes are characterized by the gradual opening of inflorescences, resulting in different snap pod formation periods, which increases the number of harvests per crop cycle. Therefore, indeterminate genotypes are more productive, and thus more commonly cultivated (QUEIROGA et al., 2003).

Vegetables, such as bush snap beans, are highly sensitive to adverse environmental conditions, such as temperature fluctuations and irregular distribution of rainfall, which compromise the availability of water to plants (FILGUEIRA, 2003). When these conditions occur during the rapid cycle of the determinate bush snap bean, they may reduce crop yield due to reduced recovery time.

Therefore, the use of management techniques seeking to favor pod yields helps to mitigate the risks in snap pod bean cultivation and can make the crop more profitable for the horticulturist. One of the techniques used to stimulate, and consequently increase the production components and yield of crops, is the application of low doses of compounds, such as hormones. These compounds at the recommended dose, or at high doses, can be toxic to plants (CALABRESE, 2005). The way in which such an effect promotes plant stimulation is not fully understood. According to Forbes (2000), the responses to this stimulus are due to the physiological attempts of the plant to compensate for its homeostasis imbalance caused by chemical stress.

According to Cedergreen (2008), low doses of herbicides, especially glyphosate, may increase biomass and crop productivity. Velini et al. (2008) and Rabello et al. (2012) observed that doses of glyphosate lower than that recommended, increased the dry mass of corn, soybean, eucalyptus, pine, coffee, citrus, and beans. Silva et al. (2012) observed that the dose of 10 g glyphosate acid equivalent (ae) ha^{-1}, applied in the last phenological stage before pre-flowering (V_4), promoted an increase in grain yield of Juriti and Pérola bean cultivars, as a function of increase in the number of grains per pod. This study is an indication that the hormone effect can also be observed in the determinate snap bean.

To increase crop productivity, studies have evaluated the application of doses of plant regulators in beans (LANA et al., 2009; BERNARDES et al., 2010; ABRANTES et al., 2011). Plant regulators such as trinexapac-ethyl and mepiquat chloride are exogenously applied synthetic substances that inhibit the common synthesis route of plant gibberellic acids, with a consequent plant size reduction (VIEIRA; CASTRO, 2002). However, when in low doses, these substances can also stimulate the development and yield of crops, because they favor the performance of metabolic reactions (LANA et al., 2009).

In legumes, applications of inhibitors of gibberellin may increase productivity due to the development of shorter and thicker stems, facilitating harvest. Meanwhile, leaves become shorter, wider, and more horizontal, resulting in greater radiation interception, thus favoring photosynthesis (LINZMEYER JUNIOR et al., 2008).

In the literature, there are few reports on the productive performance of vegetables subjected to doses of glyphosate and plant regulators. The objective of this study was to evaluate the effect of doses of glyphosate, trinexapac-ethyl, and mepiquat chloride on the growth and yield performance of determinate bush snap beans.

Material and Methods

The experiment was conducted between October and November 2014, in the municipality of Londrina-PR, Brazil, in a greenhouse located at latitude 23º19’ S, longitude 51º12’ W, and altitude of 570 m. We used the genotype of determinate bush snap bean UEL 2 (ATHANÁZIO et al., 1998), selected from the breeding program at the State University of Londrina; it has a cycle of approximately 55 days and produces butter-type pods.

Before beginning the experiment, the soil used to fill pots, classified as Dystroferric Red Latosol (EMBRAPA, 2013), was sieved in a 2 mm mesh to remove clods. Next, its chemical characteristics were determined in the 0-20 cm layer: pH ($CaCl_2$ 0.01 mol L^{-1}) 5.9; 4.28 $cmol_c$ dm^{-3} of $H^+ + Al^{3+}$; 7.7 $cmol_c$ dm^{-3} Ca^{2+}; 1.9 $cmol_c$ dm^{-3} Mg^{2+}; 0.46 $cmol_c$ dm^{-3} K^+; 17.5 mg dm^{-3} of P; 33.5 g dm^{-3} of organic matter; and 70.5% of saturation by bases. Based on the soil chemical characteristics, the basic mineral and nitrogen fertilizer applications, performed 20 days after emergence, were performed according to Parra (2003). The formulation for the basic mineral fertilizer was 10-30-10 (N-P-K), while urea (45% N) served as a source for nitrogen fertilization.

In 8 L polystyrene pots, four seeds of UEL 2 were sown. Seven days after emergence, thinning was performed to maintain two plants per pot. The pots were irrigated daily to maintain the soil at field capacity.

At the V_4 stage, the following active ingredients were dosed: a) glyphosate acid: 0.0; 18.0; 36.0; 72.0 and 144.0 g ae ha^{-1}; b) trinexapac-ethyl: 0.0; 62.5; 125.0; 250.0 and 500.0 g ae ha^{-1}; and c) mepiquat chloride: 0.0; 25.0; 50.0; 75.0 and 100.0 g ae ha^{-1}. The applications were performed with a CO_2 pressurized backpack sprayer with a pressure of 30 psi at a speed of 3.6 km h^{-1}. The volume of the syrup applied was equivalent to 200 L ha^{-1}. Before the applications, the vessels were removed and placed in an area outside the greenhouse. The products were applied between 09:00 and 10:00 in the morning, due to the lower temperature (<25° C) and low wind speed at the time of application. Subsequently, the pots were arranged randomly on the benches inside the greenhouse. The experimental design was completely randomized, with four replicates per treatment.

For glyphosate, trinexapac-ethyl, and mepiquat chloride, we used the commercial products Trop® (354.61 g L^{-1} glyphosate), Moddus® (250 g L^{-1} trinexapac-ethyl), and Pix® (250 g L^{-1} of mepiquat chloride), respectively. Herbicide doses were determined per Silva et al. (2012). The doses of trinexapac-ethyl and mepiquat chloride were based on their recommended doses for wheat and cotton crops, respectively, since recommended doses for these active ingredients do not exist for beans, and due to scarce information on their use in legumes.

We evaluated many plant characteristics: a) plant height (cm) determined by the distance from the soil surface to the apex of the main stem for the two plants in each pot, using a tape measure; b) stem diameter (cm) measured between the cotyledon node and the node of the first true leaves for the two plants in each pot, using a pachymeter; c) number of pods per plant the ratio between the number of pods and the number of plants per pot; d) pod mass per plant (g) the ratio of pod mass to the number of plants per pot; e) mean pod mass (g) the ratio between mass to the number of pods per pot; f) mean pod length (cm) the mean length of 10 pods per pot, using a ruler; g) mean pod diameter (cm) the mean diameter in the median portion of 10 pods per pot, using a pachymeter; and h) pod yield obtained by multiplying pod mass per plant and the number of plants per hectare. The data were transformed and expressed in t ha^{-1}. The number of plants per hectare was defined as 0.45 m line spacing and 0.20 m between plants.

Pods with a length equal to or greater than 10 cm in length were considered commercially viable (GOMES et al., 2016). The analysis of variance was conducted by applying the F test, and the doses were submitted to regression analysis ($p<0.05$), separately for each active ingredient.

Results and Discussion

Glyphosate

Except for mean pod mass, there was a significant effect of glyphosate doses for the other characteristics evaluated (Table 1). Despite the significance, plant height data did not fit any tested model. Regarding the control, there was a reduction of approximately 15% in plant height, regardless of herbicide dose (Figure 1A). Thus, there was no hormone effect on this characteristic. Silva et al. (2012) also did not adjust plant height data to any regression model in relation to the control and reported reductions in the performance of this trait in glyphosate acid doses ranging from 7.4 to 30.0 g ae ha^{-1} for determinate and indeterminate common bean cultivars. Therefore, based on Silva et al. (2012) and the present study, it is necessary to perform tests with doses of glyphosate acid greater than 144 g ae ha^{-1}, to verify if it is possible to identify the hormone effect on *P. vulgaris* plant height.

For stem diameter (Figure 1B), there was a quadratic adjustment with increasing doses of glyphosate acid, with a maximum response dose (MRD) of 100 g ae ha^{-1}, for a maximum stem diameter of 0.7 cm. To compensate for chemical stress caused by glyphosate, it is suggested that photoassimilates, destined to be used for plant height, were redirected to the aerial components and resulted in an increase in main stem thickness. According to Velini et al. (2008), the application of low doses of glyphosate can cause inversion of the source-drain relationship, and hence promote dry mass accumulation in plant structures, as these structures continuously receive sugars produced in photosynthesis.

There was a quadratic adjustment of the number of pods per plant with increasing doses of glyphosate acid (Figure 1C). The MRD was 20.83 g ae ha^{-1}, for a maximum number of pods per plant of 15.02, showing the hormone effect on this characteristic. Contrary to what was observed in this study, Silva et al. (2012) observed that the number of pods per common bean plant was not affected by doses varying from 7.4 to 29.6 g ae ha^{-1}. Differences in the performance of this characteristic between determinate snap beans and the common beans, compared to herbicide doses, may be related to its shorter cycle. With reduced recovery time, snap beans redirected photoassimilates for pod emission, to compensate for the alteration caused by the glyphosate

acid in its metabolism, up to the dose of 20.83 g ae ha^{-1}. From that dose, herbicide toxicity was detected in detriment of a positive change in metabolism. There was a similar pattern in the performance of pods per plant (Figure 1D).

Table 1. Analysis of variance for the agronomic characteristics of the bush snap bean UEL 2 subjected to doses of glyphosate, trinexapac-ethyl, and mepiquat chloride (Londrina-PR, Brazil, 2018).

Variation Sources	G. L.[2]	Characteristics[1]							
		PH (cm)	SD (cm)	NPP	PMP (g)	MPM (g)	PL (cm)	PD (cm)	YIE (t ha^{-1})
		Glyphosate - Mean Squares							
Repetitions	3	6.2991	0.0025	13.3000	86.3585	1.8032	1.4087	0.0117	1.0633
Sub-doses	4	48.5360*	0.0050**	131.4875**	2825.8506**	1.0549^{ns}	15.1156**	0.0690**	34.8655**
Residue	12	11.6513	0.0048	8.3625	108.5212	1.3476	1.8430	0.0116	1.3379
General Mean		42.52	0.67	12.20	49.46	4.02	11.01	0.83	5.50
CV (%)		8.03	2.97	23.70	21.06	28.87	12.33	12.95	21.05
		Trinexapac-ethyl - Mean Squares							
Repetitions	3	6.5375	0.0037	11.0791	298.7110	0.5294	0.4266	0.0039	3.6896
Sub-doses	4	26.8391^{ns}	0.0085^{ns}	48.3562*	813.4425^{ns}	0.8979*	2.8764**	0.0142**	10.0406^{ns}
Residue	12	18.0869	0.0053	13.6729	283.0248	0.2114	0.3426	0.0017	3.5003
General Mean		45.93	0.69	11.98	53.58	4.58	12.35	0.87	5.95
CV (%)		9.26	10.48	30.88	31.40	10.04	4.74	4.72	31.43
		Mepiquat chloride - Mean Squares							
Repetitions	3	22.8583	0.0048	8.6833	56.7319	0.2745	0.2550	0.0001	0.7003
Sub-doses	4	32.6828*	0.0013^{ns}	17.1875^{ns}	638.9061^{ns}	0.7953**	2.2523**	0.0189**	7.8599^{ns}
Residue	12	6.3349	0.0007	17.9958	402.7587	0.1408	0.3443	0.0015	4.9686
General Mean		45.20	0.63	14.25	63.35	4.43	12.23	0.89	7.04
CV (%)		5.57	4.34	29.77	31.68	8.47	4.80	4.37	31.67

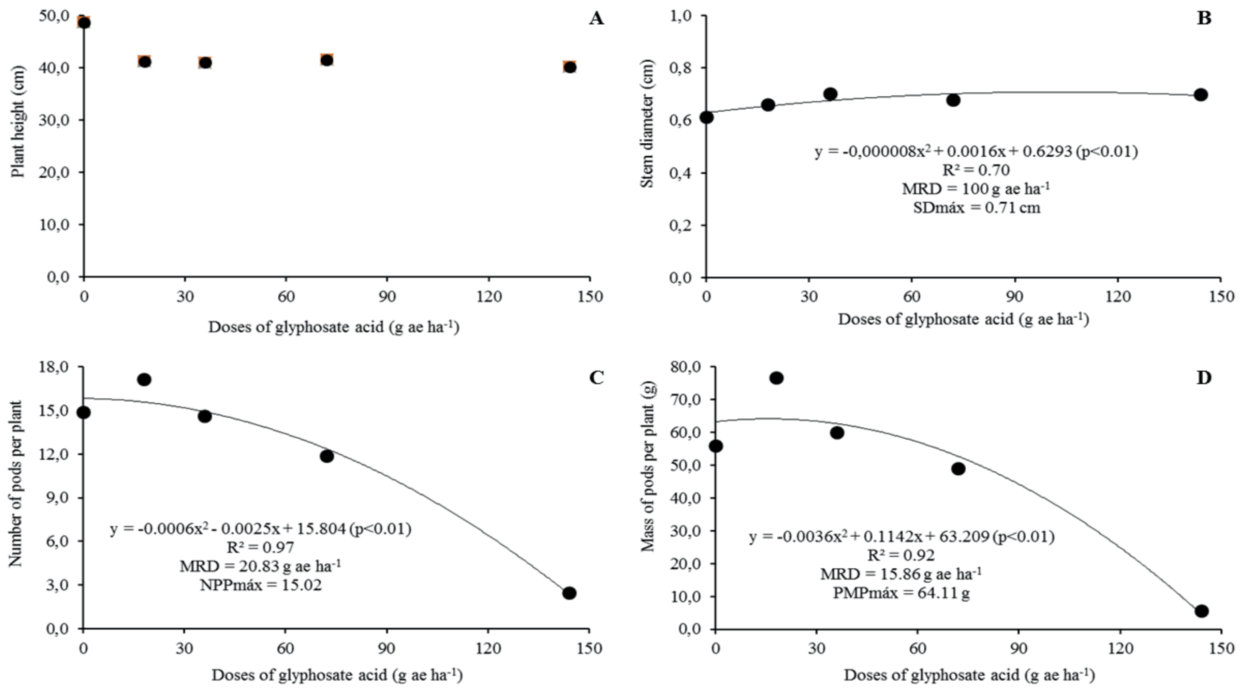
[1]PH: plant height; SD: stem diameters; NPP: number of pods per plant; PMP: pod mass per plant; MPM: mean pod mass; PL: pod length; PD: pod diameter; YIE: Yield.
[2]Degrees of freedom.
*Significant at 5% level; **Significant at 1% level.

For pod length, there was a quadratic adjustment with increasing doses of glyphosate acid, with an MRD of 42.4 g ae ha^{-1}, for a maximum pod length of 12.21 cm (Figure 1E). The same adjustment was observed for pod diameter, with an MRD of 58.0 g ae ha^{-1}, for a maximum pod diameter of 0.94 cm (Figure 1F). Thus, a hormonal effect was observed for both characteristics. Regarding the control, the length and diameter of the pod for the MRD had an increase of 11% and 30%, respectively. Evaluations of pod length and diameter are common in snap beans, as these characteristics may interfere with mass, and consequently the final yield of pods.

As for the stem diameter, for pod length and diameter, there was a quadratic adjustment for pod yield (Figure 1G). The MRD (16.0 g ae ha^{-1}) provided a maximum yield of 7.12 t ha^{-1}. This result demonstrates that there was a hormonal effect for this characteristic. In this study, the number and mass of pods per plant determined the final yield for the evaluated genotype.

For UEL 2, Gomes et al. (2016) reported a mean pod yield in Londrina of 5.68 t ha^{-1}, without using any product to stimulate production. Compared to our yield, the use of low doses of glyphosate is a management technique to increase yield, because it favors better performance of production components. However, Moreira et al. (2009) reported that UEL 2, also in Londrina and without any product to stimulate production, produced an average yield of pods of 7.33 t ha^{-1}.

Figure 1. Plant height (A), stem diameter (B), number of pods per plant (C), mass of pods per plant (D), pod length (E), pod diameter (F), and yield (G) of bush snap bean UEL 2 subjected to various glyphosate doses (Londrina-PR, Brazil, 2018).



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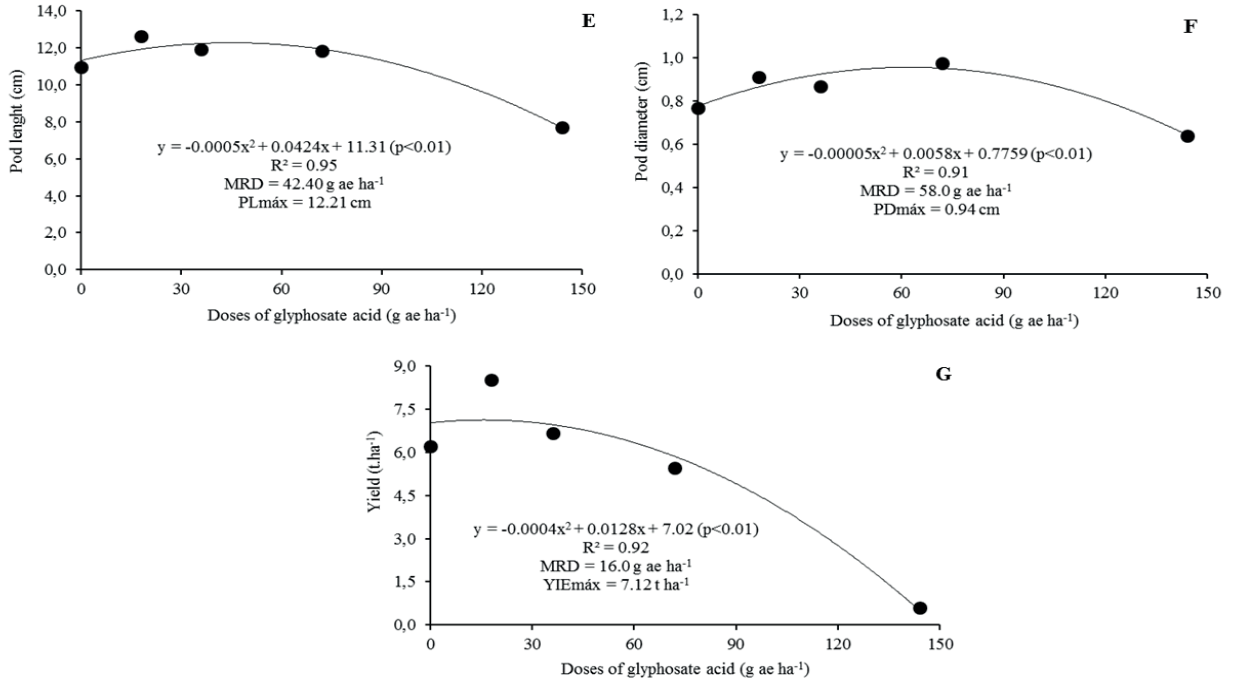


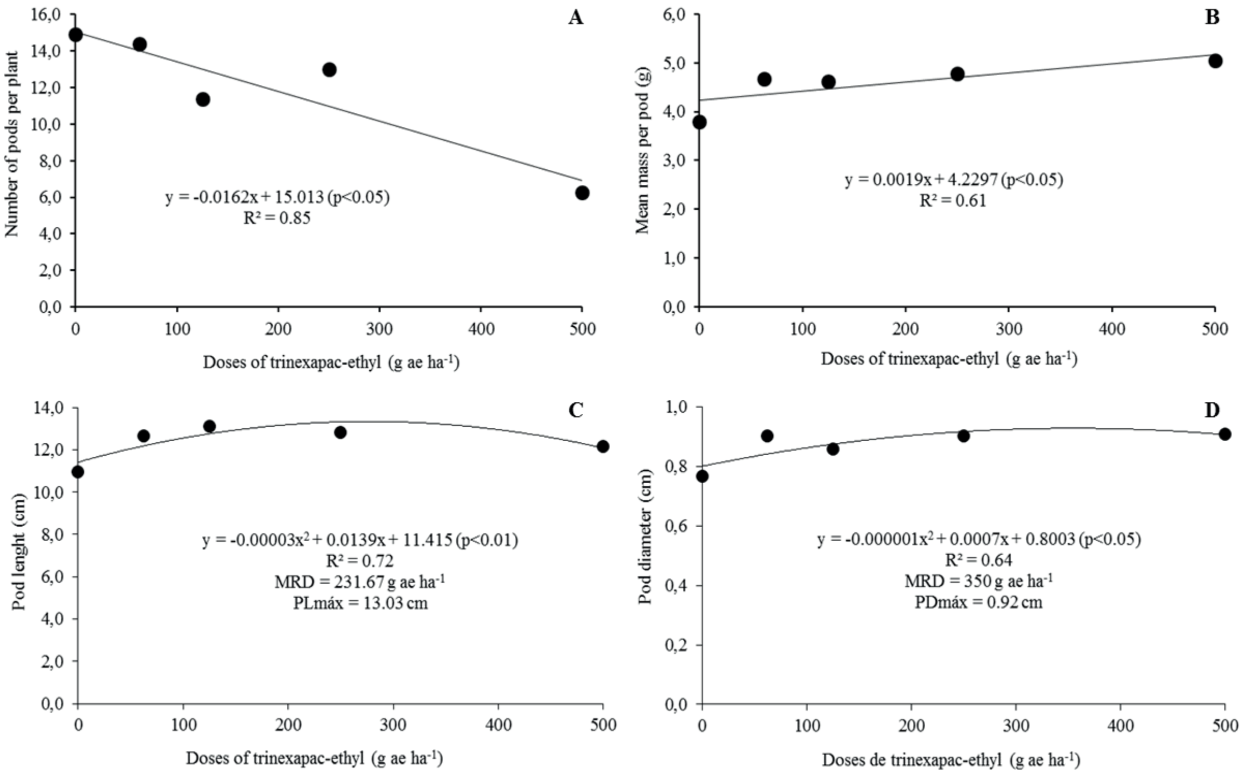
*MRD: Maximum response dose
*PMPmax: Maximum mass of pods per plant; SDmax: Maximum stem diameter; PLmax: Maximum pod length; NPPmax: Maximum number of pods per plant; PDmax: Maximum pod diameter; YIEmax = Maximum yield.

The difference in yield between Gomes et al. (2016) and Moreira et al. (2009) may be explained by the smaller line spacing used by the first authors (0.45 m × 0.50 m). The use of smaller row spacing is associated with a larger number of plants per hectare, and consequently a denser crop. Therefore, the intraspecific competition (greater abiotic stress) among plants for light, water, and nutrients is greater, and can reduce their resource-use efficiency, and hence reduce yield.

Trinexapac-ethyl

The analysis of variance (Table 1) showed a significant effect of trinexapac-ethyl doses on the number of pods per plant, mean pod mass, pod length, and pod diameter. There was a linear decrease in the number of pods per plant as the doses of trinexapac-ethyl increased (Figure 2A); the decrease was 0.016 pods to each gram of trinexapac-ethyl added. Regarding the control, there was a reduction of approximately 24% in the performance of the variable at half the recommended dose (125.0 g ae ha^{-1}); while at the recommended dose (250.0 g ae ha^{-1}), and at twice the dose (500.0 g ae ha^{-1}), reductions in the number of plant pods were, respectively, 13 and 58%. On the one hand, Souza et al. (2010) did not observe a decrease in the number of pods per common bean plant subjected to 100 g ae ha^{-1} of the plant growth regulator. On the other hand, Carvalho et al. (2014), with the same dose of the regulator in the common bean, verified a 51% increase in the number of pods per plant.

Figure 2. Number of pods per plant (A), mean pod mass (B), pod length (C), and pod diameter (D) of bush snap bean UEL 2 subjected to various doses of trinexapac-ethyl (Londrina-PR, Brazil, 2018).



*MRD: Maximum response dose

*PLmax: Maximum pod length; PDmax: Maximum pod diameter.

Contrary to the linear decrease in the number of pods per plant, there was a linear increase in mean pod mass (Figure 2B). The increase in mass was 0.002 g per gram of trinexapac-ethyl added. According to Binnie and Clifford (1999), there is an inverse relationship between number and mass of pods due to the adjustment of a bean plant between supply and demand of photoassimilates for their reproductive structures. In this study, it is suggested that the reduction in the number of pods per plant, due to the greater sensitivity of the trait to increased doses of trinexapac-ethyl (abiotic stress), altered the source-drain relationship. Thus, the plants prioritized nutrition of pods that had already been established to the detriment of new pod formation. Gomes et al. (2016) reported a similar adjustment between number and mean mass of UEL 2 due to the irregular distribution of rainfall over genotype cycle (abiotic stress). Also, regarding pod mass, it is necessary to test greater doses of trinexapac-ethyl, to obtain the inflection point of the trend line, and therefore identify the MRD to the maximum performance of this variable.

For pod length, there was a quadratic adjustment (Figure 2C), with an MRD of 231.67 g ae ha^{-1} and a maximum length of 13.03 cm; compared to the control, this is an increase of approximately 20%. Regarding pod diameter (Figure 2D), there was also a quadratic adjustment, with an MRD of 350.0 g ae ha^{-1} and a maximum pod diameter of 0.92 cm.

In summary, the application of trinexapac-ethyl doses within the range used in this study, as well as that of 231.67 and 350.0 g ae ha^{-1}, improved the performance of mean pod mass, pod length, and pod diameter. Thus, the use of trinexapac-ethyl doses in determinate snap beans may increase mean pod mass, but not necessarily crop yield.

Mepiquat chloride

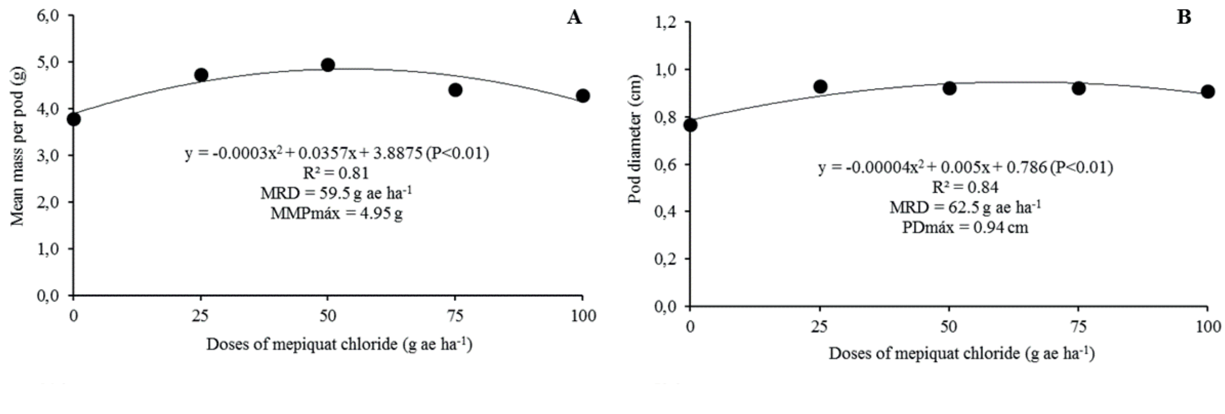
The doses of mepiquat chloride provided significant changes in the performance of plant height, mean pod mass, pod length, and pod diameter (Table 1). In the literature, there are few reports on the performance of bean, either for snap pods or grains, subjected to mepiquat chloride. In cotton, Américo (2015) observed a reduction in plant height of 14.26 cm with the application of 50 g ae ha^{-1}.

For mean mass pod, there was a quadratic adjustment, with an MRD of 59.5 g ae ha^{-1} and a maximum weight of 4.95 g (Figure 3B), a 30% increase compared to the control. According to the manufacturer's recommendation for cotton, a single application of 200 mL of Pix HC® per hectare, equivalent to 50 g ha^{-1} of mepiquat chloride, is indicated to improve the retention of flower buds and apples. Regarding trinexapac-ethyl, the supplemental use of mepiquat chloride in snap bean may increase mean pod mass, which may or may or not be associated with the number of pods per plant, but not the yield.

Per mepiquat chloride doses, there was a quadratic adjustment for the length and diameter of the pod (Figures 3C and 3D), with maximum pod length at 62.4 g ae ha^{-1} and maximum pod diameter at 62.5 g ae ha^{-1}. The performance of these variables was similar to the performance of mean pod mass: as mepiquat chloride doses increased up to 59.5 g ae ha^{-1}, mean pod mass increased. This is explained by the relationship between pod size and mass.

The use of low doses of glyphosate, trinexapac-ethyl, and mepiquat chloride altered the physiology of the determinate bean plant. Glyphosate increased the performance of production and yield components;

Figure 3. Plant height (A), mean pod mass (B), pod length (C), and pod diameter (D) of bush snap bean UEL 2 subjected to various doses of mepiquat chloride (Londrina-PR, Brazil, 2018).



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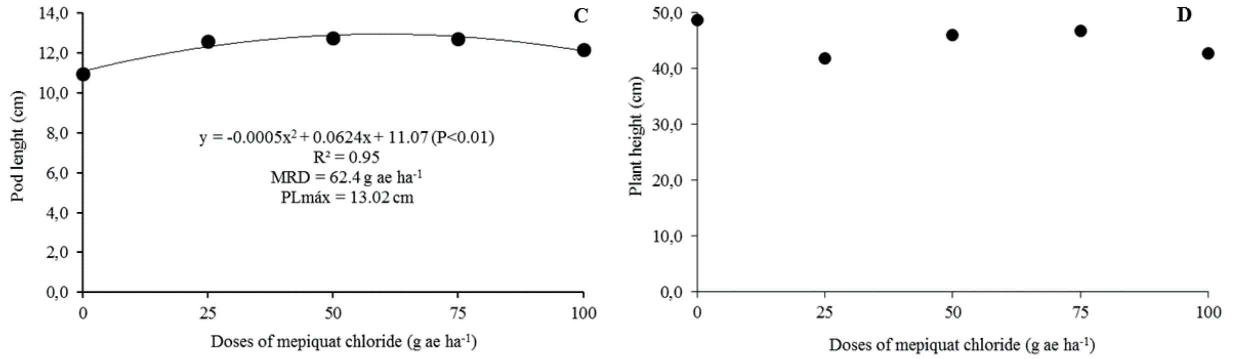

*MRD: Maximum response dose
*MMPmax: Maximum mean mass per pod; PLmax: Maximum pod length; PDmax: Maximum pod diameter.

while trinexapac-ethyl and mepiquat chloride positively influenced some production components, but without significantly improving yield. Hence, field studies are required to verify and validate our greenhouse results, as well as to establish safety intervals between the time of application and the harvest and consumption of pods, considering that the products were used at low doses.

Conclusions

The productive performance of the determinate bush snap bean was improved by applying glyphosate at doses up to 16.0 g ae ha^{-1}, as demonstrated by increased pod mass per plant and pod yield. Increased doses of trinexapac-ethyl reduced the number of pods per plant and increased mean pod mass. Doses of mepiquat chloride up to 59.5 g ae ha^{-1} increased mean pod mass. Finally, determinate bush snap bean pod yield is not influenced by plant growth regulators trinexapac-ethyl and mepiquat chloride.

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