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ORIGINAL PAPER

Foliar Fertilization with Boron on the Growth, Physiology, and Yield of Snap Beans

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Abstract
The snap bean is a vegetable of great worldwide economic importance. However, tropical soils have low amounts of nutrients, especially boron, a micronutrient essential for plant nutrition. The objective of this work is to verify the effects of foliar application of boron on the growth, physiology, nutrition, and productivity of snap beans. The experiment was carried out in a greenhouse in a completely randomized design, with five treatments comprising boron doses (0 – control, 1350, 2700, 4050, and 5400 ppm) and four replicates. Foliar application of boron was carried out at the V3 vegetative stage (third mature trifoliate). Growth, physiological, nutritional, and productivity variables were evaluated at the reproductive stages R5 (flowering) and R8 (harvest). Data were subjected to analysis of variance and F test at a 5% significance level. When significant, data was submitted to Student t, Scott-Knott, and regression analysis. Doses above than 2700 ppm affected significantly foliar temperature, transpiration, stomatal conductance, photosynthesis, and internal carbon concentration of bean pods. Foliar fertilization with boron influenced significantly the content and accumulation of boron in the shoot (868%) and the root system (105%), but it did not change the contents in pods. However, although they affect the physiology of snap bean plants, the tested doses did not influence significantly the growth variables and productivity. Boron doses from 2700 ppm caused symptoms of phytotoxicity on snap bean crops. Therefore, we do not recommend foliar application of boron at the stage V3 in snap bean crops even with a low boron content in the soil.

Keywords *Phaseolus vulgaris* · Plant nutrition · Micronutrient · Nutrition efficiency · Physiology

1 Introduction

The snap bean (*Phaseolus vulgaris* L.) is a horticultural legume with a global economic importance. Its center of origin is the Americas (Vaz et al. 2017). It has a high profitability due to its short cycle and its high productivity. There is a high demand in the international market (Seif et al. 2016).

Tropical soils have a low natural fertility and are poor in organic matter. They are deficient in some micronutrients, which may limit the productivity of crops (Gomes et al. 2017). Currently, several researchers have been studying the application of micronutrients, among them boron, seeking to increase productivity and production quality. Boron plays a key role in the metabolism of plants, including the formation and stability of the cell wall, which maintains the integrity of membranes, sugar and energy drive, pollination, pod fixation, and increased grain yield per plant, resulting in improvements in productivity (Flores et al. 2017; Santos et al. 2019).

In the soil, the availability of boron is conditioned to the pH and the organic matter content. Therefore, it is not always present in necessary quantities for the growth of plants. The foliar application is an alternative to improve its use by crops. In this context, the application of foliar fertilizers with micronutrients has increased in recent years due to the need to seek high crop yields (Nakao et al. 2018). However, due to the low mobility of B in plant tissues, foliar fertilization may be an obstacle to plant nutrition (Mantovani et al. 2013), thus requiring studies to verify whether it is a viable practice. The lack of consistent results on boron foliar application leads to discussions about the viability of this technique (Santos et al. 2019).

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Thus, further studies are needed on the management of fertilizers containing micronutrients, especially boron, due to its narrow range between the critical level of deficiency and the excess (Flores et al. 2018). Further studies are needed especially on snap beans, for there is no research on the subject. Thus, this study aims to verify the effects of foliar application of boron on growth, physiology, nutrition, and productivity of snap beans.

2 Material and Methods

2.1 Site Description and Soil

The experiment was carried out in a greenhouse at the Federal University of Goiás, Campus Samambaia, in the city of Goiânia, GO, Brazil (16°35′46.2″ S and 49°16′47.1″ W, approximately 730 m above sea level). The climate is Aw, with dry winters and rainy summers, according to the Köppen classification.

The soil was collected at the superficial layer (0–20 cm). It is a Rhodic Hapludox (Taxonomy 2006). It was deformed, homogenized, passed through a 4-mm sieve, and placed in a pot filled with 14 kg of soil. Prior to the installation of the experiment, the soil presented the following chemical and physical parameters: pH-$CaCl_2$ = 5.0, Ca = 3.1 $cmol_c\ dm^{-3}$, Mg = 1.1 $cmol_c\ dm^{-3}$, Al = 0.1 $cmol_c\ dm^{-3}$, P = 2.1 mg dm^{-3}, K = 20 mg dm^{-3}, H + Al = 2.3 mg dm^{-3}, Cu = 2.9 mg dm^{-3}, Fe = 86 mg dm^{-3}, Mn = 27 mg dm^{-3}, Zn = 0.7 mg dm^{-3}, B = 0.251 mg dm^{-3}, cation exchange capacity = 6.8 $cmol_c\ dm^{-3}$, base saturation = 65.9%, organic material = 14.0 g kg^{-1}, and clay = 320 g kg^{-1}.

2.2 Experimental Design

We used a completely randomized design with five treatments and four replications. The treatments consisted of five doses of boron (0 – control, 1350, 2700, 4050, and 5400 ppm) applied via foliar at the V3 vegetative stage (third mature trifoliate).

The planting was carried out on March 26, with four seeds per pot. At the same time, fertilization was carried out with 30 kg ha^{-1} of N, 90 kg ha^{-1} of P_2O_5, and 40 kg ha^{-1} of K_2O, using urea (45% N), triple superphosphate (46% P_2O_5), and potassium chloride (60% K_2O), respectively, as fertilizers (Souza and Lobato 2004). The cultivar used was the "Celtic," with a prostrate growth habit, a good uniformity of pods, dark green color, and of a noodle type.

Seedling thinning was performed 7 days after emergence, leaving two plants per pot. At the V3 vegetative stage (third mature trifoliate), the fertilization was performed with 30 kg ha^{-1} of N using urea as fertilizer (Souza and Lobato 2004). At V3, foliar application of boron was also performed using as source borax (11% boron). Borax was used due to its higher water solubility compared to boric acid. It was performed by single application in the morning using a sprayer. During the application of foliar fertilization, the pots were covered with a plastic film to prevent contact of the product with the pots.

2.3 Plant Analysis

At R5 stage (flowering), growth parameters were measured, such as height, collection diameter, number of triphols (composite leaf with three leaflets), number of flowers, and leaf area. The leaf area was estimated by the nondestructive method proposed by Queiroga et al. (2003) using Eq. 1:

$$\text{Leaf area} = 0.1026 \text{ x width}^{1.6871} \tag{1}$$

The physiological parameters (leaf temperature, photosynthesis, transpiration, stomatal conductance, internal CO_2 concentration) were measured using the infrared gas analyzer (IRGA, Li-COR, Lincoln, USA) and the chlorophyll content by a chlorophyll meter (FALKER®, ClorofiLOG CFL 1030). Subsequently, a plant was removed per pot and washed to remove debris and then sent for drying in a closed air circulation oven at 60 °C for 72 h to obtain the dry mass of shoots. The plant tissue sample was incinerated in an electric muffle at a temperature between 500 and 550 °C. The resulting ash was dissolved in dilute acidic nitric solution. The determination of boron was based on the formation of a yellow-colored complex resulting from the reaction of boric acid with azomethine-H reagent and determined spectrometrically in blue filter readings at 420 nm (Silva 2009).

The harvest of the pods was performed during the stage R8 (harvest point – pods around 8 cm), when the pods reached a commercial size. The growth,

Table 1 Height, diameter, number of triphols (composite leaf with three leaflets), and leaf area in the absence and presence of leaf fertilization with boron in snap bean crops at the stages R5 (flowering) and R8 (harvest)

Boron	Height (cm)	Diameter (mm)	*N*° triphols	Leaf area (cm^2)
Stage	R5			
Absence	37.25 ± 3.24	4.45 ± 0.18	4.75 ± 0.48	5.19 ± 0.91
Presence	37.00 ± 1.25	4.29 ± 0.17	3.75 ± 0.67	4.34 ± 0.94
F	0.94^{ns}	0.35^{ns}	0.11^{ns}	0.38^{ns}
CV	14.97	10.63	30.13	44.2
Stage	R8			
Absence	36.50 ± 2.10	5.33 ± 0.15	6.25 ± 0.28	24.97 ± 2.29
Presence	36.12 ± 1.47	5.09 ± 0.18	6.87 ± 0.40	20.22 ± 2.51
F	0.87^{ns}	0.49^{ns}	0.48^{ns}	0.30^{ns}
CV	14.45	7.48	31.13	29.55

**significant at 5% of probability by the t test; *ns* not significant at 5% probability by the t test; *CV* coefficient of variation (%)

Table 2 Chlorophyll, shoot dry mass (SDM), and root dry mass (RDM) in the absence and presence of leaf fertilization with boron in snap bean crops at the stages R5 (flowering) and R8 (harvest)

Boron	Chlorophyll (µg cm^{-2})	SDM (g)	RDM (g)
Stage	R5		
Absence	18.17 ± 3.26	1.64 ± 0.23	0.62 ± 0.15
Presence	18.18 ± 0.89	1.55 ± 0.15	0.61 ± 0.14
T	0.99^{ns}	0.55^{ns}	0.76^{ns}
CV	23.37	10.16	6.68
Stage	R8		
Absence	21.45 ± 2.29	3.77 ± 0.18	1.16 ± 0.10
Presence	21.65 ± 1.81	3.72 ± 0.11	1.19 ± 0.12
F	0.96^{ns}	0.89^{ns}	0.85^{ns}
CV	21.56	20.31	40.43

**significant at 5% of probability by F test; *ns* not significant at 5% probability by F test; *CV* coefficient of variation (%)

physiological, and nutritional analyses described above were carried out, plus analysis of productivity variables: number of pods per plant, pod size, pod diameter, green mass, and dry pod mass. The boron use efficiency was calculated by Eq. 2, as described by Siddiqi and Glass (1981):

$$\mathrm{BUE} = (\mathrm{TDM})2/\mathrm{TAB} \tag{2}$$

where BUE is the boron use efficiency, TDM is the total dry mass produced by the plant, and TAB is the total accumulation of boron in the plant.

2.4 Statistical Analysis

The data were submitted to analysis of variance and F test at 5% of significance using the R software. A t test was performed to compare the absence and presence of boron foliar fertilization, and the Scott-Knott test was used to verify differences between doses and the control. When significant, the polynomial regression analysis was performed (5% of significance).

3 Results

Foliar fertilization with boron did not have statistical differences (5% of significance) in relation to the growth of bean pods, according to Table 1. However, it is possible to observe that for doses above 2700 ppm, there is a reduction in the values of the variables, showing a possible effect of toxicity. According to Table 2, boron doses did not influence chlorophyll content, leaf area, and dry weight of shoots in snap bean plants, showing that there was no influence on the accumulation of biomass.

Table 3 shows significant differences (5% of significance) among physiological variables in function of boron doses. In relation to the internal carbon concentration (Ci), at the R5 stage, there was a linear reduction of 29% of the Ci (Fig. 1a) and a quadratic adjustment with a minimum of 2100 ppm at the R8 stage (Fig. 1b).

Table 3 Foliar temperature (T), concentration internal of CO$_2$ (Ci), transpiration (E), stomatal conductance (Gs), and photosynthesis (A) with different doses of leaf fertilization with boron in snap bean crops at the stages R5 (flowering) and R8 (harvest)

Dose (ppm)	T °C	Ci (mmol m^{-2} s^{-1})	E (mmol H$_2$O m^{-2} s^{-1})	Gs (molm^{-2} s^{-1})	A (µmolm^{-2} s^{-1})
Stage	R5				
0	40.1 ± 0.23	252.6 ± 5.00	2.7 ± 0.25	0.22 ± 0.02	15.1 ± 1.82
1350	40.7 ± 0.02	228.5 ± 16.22	3.2 ± 0.13	0.25 ± 0.02	19.7 ± 0.60
2700	40.9 ± 0.11	237.7 ± 6.58	3.5 ± 0.29	0.28 ± 0.01	19.8 ± 1.11
4050	40.1 ± 0.13	177.3 ± 23.07	2.5 ± 0.25	0.19 ± 0.02	20.5 ± 2.63
5400	40.8 ± 0.11	186.9 ± 15.01	2.3 ± 0.97	0.42 ± 0.20	21.3 ± 0.93
F	7.17**	5.12**	1.34^{ns}	1.17^{ns}	2.34^{ns}
CV	0.71	13.39	29.4	59.27	16.34
Stage	R8				
0	27.6 ± 0.03	199.5 ± 7.46	1.43 ± 0.12	0.24 ± 0.03	20.6 ± 1.32
1350	28.2 ± 0.14	80.7 ± 31.05	1.23 ± 0.14	0.17 ± 0.04	24.1 ± 1.76
2700	28.5 ± 0.12	93.3 ± 16.58	0.53 ± 0.07	0.05 ± 0.01	13.8 ± 1.67
4050	29.9 ± 0.14	214.1 ± 33.75	1.85 ± 0.06	0.23 ± 0.02	17.8 ± 3.52
5400	30.4 ± 0.02	222.6 ± 16.45	1.79 ± 0.13	0.18 ± 0.02	16.1 ± 2.35
F	12.54**	8.45**	26.27**	9.63**	3.10**
CV	0.73	29.35	15.53	28.46	24.58

**significant at 5% of probability by the Scott-Knott test; *ns* not significant at 5% probability by the Scott-Knott test; *CV* coefficient of variation (%)

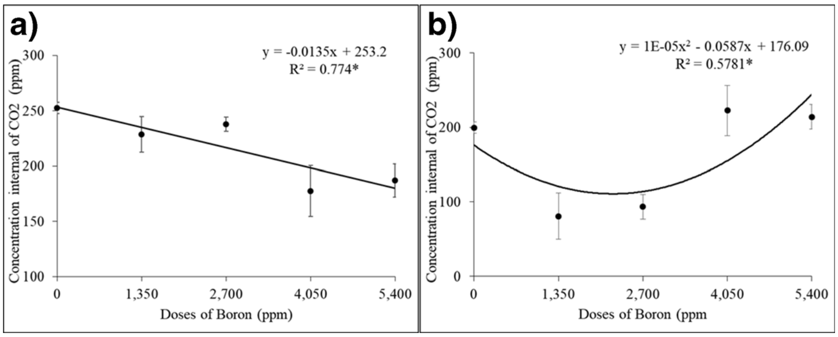

Fig. 1 Internal concentration of CO_2 at R5 (flowering) (**a**) and R8 stages (harvest) (**b**) in function of boron doses in snap bean plants. *Significant at 5% of probability

Leaf temperature, transpiration, and stomatal conductance were significant only at the R8 stage. Regarding leaf temperature (Fig. 2a) (at the R8 stage, there was a linear increase of this variable with the increase of boron doses) and stomatal conductance (Fig. 2b), they showed a quadratic fitting of regression, with a reduction of the means of the variables up to the dose 2.10 kg ha^{-1}. For photosynthesis (Fig. 2c), there was an opposite behavior. Doses up to 3.29 kg ha^{-1} promoted an increase in the photosynthetic rate of snap beans.

In relation to the content and accumulation of boron in the plant, it is possible to observe a significant difference (5% of significance) in the shoots of snap beans at the R5 stage, in which it promoted increases of 1032% and 868% when comparing the 5400-ppm dose with 0 ppm, respectively (Table 4).

The content of B in shoots showed a linear behavior in function of the applied dose (Fig. 3a), with a greater accumulation at the dose 4198 ppm (Fig. 3b). However, in the analysis performed at the R8 stage, only the roots had a significant result, with a maximum B content of 3915 ppm (Fig. 4). In snap beans, boron accumulation is mainly concentrated in shoots (58%), followed by pods (22%) and roots (20%).

Foliar fertilization with boron did not affect significantly (5% of significance) the productive characteristics of bean pods, according to Table 5, which shows that the application performed at the V3 stage is incapable of promoting an increased crop productivity.

The leaf application of boron promoted visual symptoms of toxicity in bean leaves mainly at doses above 2700 ppm. There were chlorotic spots followed by necrosis on old leaves, as shown in Fig. 5.

4 Discussion

Although the concentration of boron in the soil was considered low, it was enough to supply the necessary amount for an adequate development of plants, even in the treatment without fertilization (Çelik et al. 2019). The nonsignificant effect of borated foliar fertilization

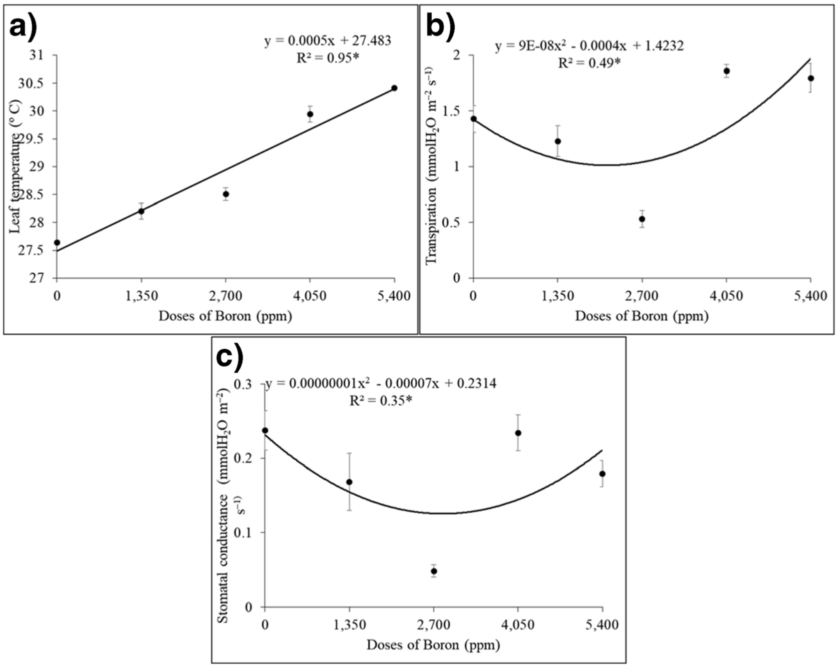

Fig. 2 Leaf temperature (**a**), transpiration (**b**), and stomatal conductance (**c**) at the stage R8 (harvest) in function of boron doses in snap bean plants. *Significant at 5% of probability

Table 4 Boron content and boron accumulation in shoots, roots, and pods at the R5 (flowering) and R8 (harvest) stages, boron utilization efficiency (BUE), and total boron accumulation in function of boron doses

Dose	Shoots	Shoots	Roots	Pods	BUE
ppm	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g^{2} mg^{-1}
Stage	R5	R8	R8	R8	R8
Boron content					
0	30.8 ± 6.76	22.3 ± 2.71	23.6 ± 1.07	19.4 ± 4.17	37.1 ± 4.46
1350	248.3 ± 52.76	34.1 ± 6.27	48.2 ± 3.50	13.3 ± 1.92	23.8 ± 3.58
2700	257.3 ± 48.57	26.5 ± 2.36	31.9 ± 5.05	16.5 ± 2.75	35.1 ± 4.19
4050	348.9 ± 50.98	49.7 ± 10.51	39.6 ± 2.73	18.1 ± 2.08	16.8 ± 0.74
5400	319.5 ± 22.91	34.1 ± 10.89	41.4 ± 4.33	21.3 ± 4.47	26.7 ± 3.42
F	9.57**	2.14^{ns}	6.31**	0.99^{ns}	5.72**
CV	33.48	72.34	20.34	34.43	24.97
Boron accumulation					
0	177.7 ± 40.97	85.4 ± 14.29	27.4 ± 2.76	56.4 ± 14.26	169.2 ± 11.19
1350	1405 ± 337.91	109.0 ± 14.36	44.3 ± 4.27	31.9 ± 8.45	185.3 ± 22.52
2700	1432 ± 296.10	119.8 ± 18.58	49.2 ± 10.01	43.6 ± 10.09	212.6 ± 19.03
4050	1969 ± 304.35	177.4 ± 46.77	36.9 ± 9.92	37.0 ± 9.99	251.1 ± 54.35
5400	1720 ± 103.45	124.5 ± 48.07	56.3 ± 19.82	61.0 ± 19.82	241.8 ± 54.07
F	7.77**	1.28^{ns}	4.30**	0.87^{ns}	0.97^{ns}
CV	36.92	48.56	25.15	57.78	33.76

**significant at 5% of probability by the Scott-Knott test; *ns* not significant at 5% probability by the Scott-Knott test; *CV* coefficient of variation (%)

on plant growth corroborates the results found by Nakao et al. (2018) and Gomes et al. (2017), according to which plant height and stem diameter were not affected by doses of boron in soybean. However, it differs from that found by Pawlowski et al. (2019) for soybean. The authors found an increase in the height of plants according to the dose of B applied.

Increases in growth rate with foliar application over the basal dose were due to an improved physiological efficiency that played a significant role in increasing crop productivity (Mondal et al. 2012). However, boron toxicity can be an obstacle for a longitudinal growth of roots; toxicity can decrease cell division and root growth because excessive amounts create disorders in the process of cell wall development (Rostami et al. 2017).

Regarding the physiology of snap bean plants, the application of boron did not affect the relative chlorophyll content, which is strongly correlated with nitrogen content. The borated fertilization had no influence on the metabolism of N (Flores et al. 2017; Flores et al. 2018). Çelik et al. (2019) and Pawlowski et al. (2019) claim that high doses of boron may promote toxicity. One of the effects is the reduction in the photosynthetic rates of the plant, as observed in this experiment.

Reductions of photosynthesis are associated with boron stress and enhanced activities of antioxidant enzymes. Catalase and guaiacol peroxidase showed a typical stress response (Ou et al. 2019). The decrease in photosynthesis rates under stress conditions can be attributed to injuries in the structure of thylakoids, which affect electron transmission, decrease Fv/Fm (Rostami et al. 2017), and may have changed leaf temperature, stomatal conductance, and transpiration at the R8 stage.

The activation of stress-related genes and antioxidant enzymes could help to protect plants against excess of B (Aydin et al. 2019). Some biological processes may be crucial in

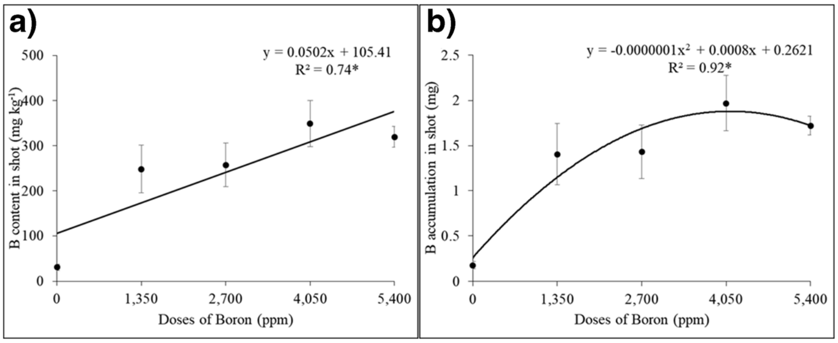

Fig. 3 Boron content (**a**) and accumulation (**b**) of boron in shoots at the R5 (flowering) stage in snap bean plants in function of the foliar application of increasing doses of boron. *Significant at 5% of probability

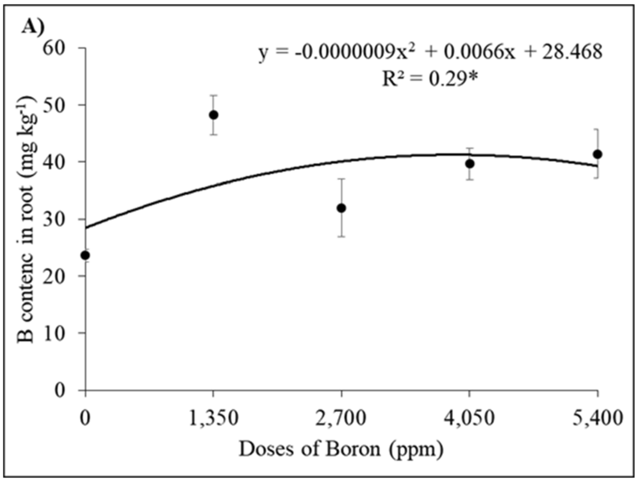

Fig. 4 Boron content in the roots at the stage R8 (harvest) in snap bean plants in function of foliar application of increasing doses of boron. *Significant at 5% of probability

regulating B homeostasis in plants, such as antioxidant mechanism, energy metabolism, protein degradation, lipid biosynthesis, and signaling pathways (Tombuloglu et al. 2017). In addition, phylogenetics and expression are possibly involved in the regulation of the toxicity tolerance mechanism of B, relating to a MYB family of transcription factors (Tombuloglu et al. 2013). Genes play crucial roles in stress response in excess of B mainly related to stress response, cell wall, plasma membrane, cytoskeleton construction, Ca^{2+}/calmodulin system, phospholipase activity, and signal transduction (Tombuloglu et al. 2015).

The increase in foliar boron content in function of the doses at the R5 stage corroborates Mantovani et al. (2013), Gomes et al. (2017), and Silva et al. (2017), for whom the foliar content of B increases linearly with the applied dose. Pawlowski et al. (2019) observed that, in addition to increasing leaf content, boron foliar application is capable of increasing nutrient contents in roots and seeds.

Foliar fertilization with boron may induce the translocation of leaf boron to other parts of the plant, which is a proof of the mobility of boron in the phloem of some species (Gürel et al. 2019) or an attempt by the plant to reduce the effects of phytotoxicity. Hegazi et al. (2018) concluded that boron is mobile as reproductive organs accumulated more boron than vegetative organs. However, the increase in B concentrations tends to decrease its use efficiency, since with a greater amount of nutrient, there is a slight increase or even a reduction in the production of dry mass (Flores et al. 2018).

The fact that the boron doses do not result in total nutrient accumulation in pod beans may be related to the dilution effect that occurs along with plant growth, reducing the boron content when comparing the R5 with the R8 stage. The lack of mobility of boron in the phloem is a related problem. It limits its location after the foliar application mainly on old leaves, in which they suffer senescence over time. With this, the trifolia that emerged after the application were not influenced by the foliar fertilization of B. Furthermore, the aggregate B in its root prevents the translocation and mechanisms of internal tolerance use exclusion. As a result, there is a decrease in the amount of B accumulation in the whole plants (Rostami et al. 2017).

A similar result was found by Flores et al. (2018). The borated application, despite increasing leaf contents, was not able to influence the accumulation of the nutrient in the shoots, roots, and total plant. Thus, the nutrient tends to be retained in the place where it was applied, and due to its low translocation, the nutrient distribution does not occur to all organs at necessary amounts (Fioreze et al. 2018).

The absence of responses of the variables related to the production in function of boron doses applied via boron leaf corroborates several authors. Gomes et al. (2017), Silva et al. (2017), Nakao et al. (2018), and Santos et al. (2019) did not find significant productivity differences in relation to the boron doses applied in soybean crops. Lima et al. (2018), although they observed an increase in the number of grains per pod,

Table 5 Number of flowers (NF), number of pods (NP), mean pod length (MPL), mean pod diameter (MPD), pod green mass (PGM), pod dry mass (PDM), and estimated yield at different doses of boron applied via leaf in snap beans

Dose	NF	NP	MPL	MPD	PGM	PDM	Yield
ppm	–	–	cm	mm	g	g	$kg\ ha^{-1}$
0	3.50 ± 2.37	8.25 ± 1.03	8.17 ± 0.35	7.03 ± 0.23	2.51 ± 2.27	0.35 ± 0.26	1272.1 ± 118.32
1350	5.25 ± 1.99	6.50 ± 0.64	8.96 ± 0.46	6.79 ± 0.44	2.09 ± 1.57	0.34 ± 0.33	1000.8 ± 147.81
2700	5.00 ± 1.07	7.00 ± 0.82	9.45 ± 0.59	7.02 ± 0.42	2.73 ± 1.99	0.37 ± 0.23	1130.5 ± 102.00
4050	4.75 ± 3.45	6.00 ± 0.71	8.95 ± 1.05	6.36 ± 057	1.86 ± 3.51	0.32 ± 0.42	873.9 ± 185.55
5400	6.50 ± 2.44	6.00 ± 0.76	9.13 ± 0.43	7.35 ± 0.49	2.56 ± 1.03	0.49 ± 0.2	1210.17 ± 106.29
F	$0,50^{ns}$	0.91^{ns}	0.11^{ns}	0.73^{ns}	1.61^{ns}	2.71^{ns}	1.23^{ns}
CV	60.55	29.07	15.99	13.08	23.85	21.7	40.14

**significant at 5% of probability by the Scott-Knott test; *ns* not significant at 5% probability by the Scott-Knott test; *CV* coefficient of variation (%)

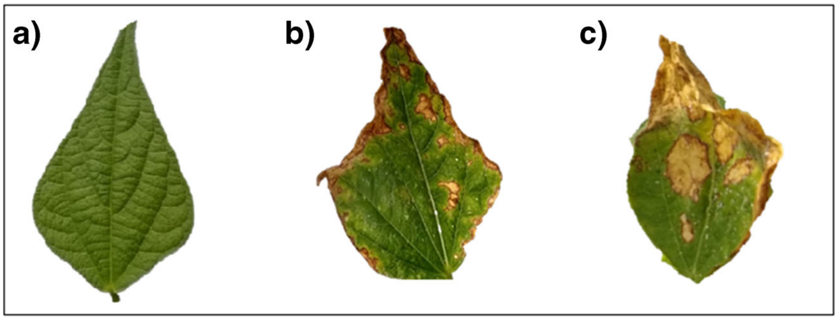

Fig. 5 Healthy leaf (**a**), initial symptoms (**b**), and evolution (**c**) of the phytotoxicity of leaf application of boron in snap bean plants

reported that the borated fertilization did not influence the final yield in bean crops. Mantovani et al. (2013) verified that the application of B in leaves at a single dose is not able to increase peanut productivity regardless of the dose used, but the splitting of foliar fertilization is capable of promoting yield increases.

The symptoms of phytotoxicity corroborate Rostami et al. (2017). The burning started on the tip and the margin of young leaves and moved to old leaves. Despite the appearance of symptoms, especially at the R5 stage, boron toxicity in old leaves cannot mean excess in the whole plant due to a limited mobility of the nutrient in the phloem (Flores et al. 2017), a fact confirmed by the absence of statistical differences in the total boron accumulation in the plant at the R8 stage. Boron toxicity symptoms occur in the marginal region of old leaves. These portions become chlorotic or necrotic because boron is transported and accumulates along the transpiration pathways (Ozturk et al. 2010). In general, the lower boron doses were more effective than the higher doses, with total chlorophyll, chlorophyll a and b, and total soluble sugars significantly increased as the boron application rate increased (Hegazi et al. 2018).

5 Conclusions

Foliar fertilization with boron does not influence snap bean growth, but affects its physiology, mainly the internal CO_2 concentration. Bean pods show a high accumulation of boron at the R5 (flowering) stage depending on foliar application. B promotes phytotoxicity at doses above 2700 ppm. The application of boron via leaves does not promote the increase in snap bean crop yield. Therefore, we do not recommend foliar application of boron at the vegetative stage V3 (third mature trifoliate) in snap bean crops even with a low boron content in the soil.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

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