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Agronomic performance of common bean (*Phaseolus vulgaris* L.) according to foliar application of potassium silicate in two sowing times

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Common bean (*Phaseolus vulgaris* L.) cultivation is of relevant economic importance for Brazil, since this legume is one of the main Brazilian staple foods. The objective of this study was to evaluate, in two sowing times, the agronomic performance of two bean cultivars according to foliar application of different doses of potassium silicate. Experiments were conducted under field conditions, in the rural area of the city of Assis Chateaubriand, Paraná, Brazil. The first experiment was implanted in August, 2014 (rainy season crop) and the second one was implanted in February, 2015 (dry season crop). A randomized block design was used in both experiments, in a 2 × 5 factorial design, with four replications. The first factor refers to common bean cultivars (IPR Campos Gerais and IPR Tuiuiú) and the second factor refers to the different doses of potassium silicate (0.0, 250, 500, 750 and 1000 ml ha^{-1}). The product used contained 0.9 w/v of SiO_2 (90 g L^{-1} of water) and 18% K_2O in its formulation. The agronomic characteristics evaluated were plant height, dry matter weight of the aerial parts, amount of pods per plant, thousand grain weight, and grain yield. Foliar fertilization with potassium silicate did not influence the agronomic characteristics of common bean cultivars. Regardless of foliar application with potassium silicate, IPR Campos Gerais cultivar presented greater plant height, thousand grain weight and grain yield for rainy season crop when compared with IPR Tuiuiú cultivar, which in turn presented higher productivity in dry weather crop.

Key words: IPR Campos gerais, IPR Tuiuiú, silicon.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is cultivated in nearly all regions of Brazil by small and large producers, in different production systems, due to its edaphoclimatic adaptation (Moura et al., 2015). Thus, there is the importance of having a previous knowledge about soil and weather of the region in which common bean will be cultivated, as well as about the cultivation requirements and limitations, in order to choose a proper environment for plants to grow, develop and produce evenly, and to take full advantage of inputs and of benefits from other practices or technologies applied (Andrade et al., 2015).

Being a day-neutral plant, in Brazil, common bean is cultivated in three different sowing times: the first time is called "Safra das águas" (rainy season crop, or Southern and Southeastern crop); the second time is called "Safra das Secas (dry season crop, also called Second crop or Northeastern and Southeastern crop); the third time is called "Safra de outono-inverno" (fall-winter crop, also called Southeastern crop or irrigated crop) (Moura et al., 2015).

An alternative management for this leguminous plant is the adoption of foliar fertilization with some micronutrients, such as silicon (Si). The main feature of Si is to act as a plant resistance inducer, making plants more tolerant to climatic stresses and even to pest attacks and diseases. The way by which Si exerts a protective effect against pathogens and insects is still not defined (Ghanmi et al., 2004; Goussain et al., 2005). However, protection conferred to plants by Si is considered to be due to the accumulation and polymerization of this element in plant cells, creating a mechanical barrier which hinders insect pest attacks and pathogens (Yoshida et al., 1962). Silicon's role as a mechanical resistance enhancer was questioned by Menzies et al. (1991) and Samuels et al. (1991). According to Chérif et al. (1992), Si is related to specific defense reactions of plants. According to Gomes et al. (2005), this element acts as an elicitor of induced resistance mechanism in plants.

According to Marschner (1995) and Malavolta (2006), Si is characterized as a beneficial element for plants, as it confers increased resistance against pest attacks and diseases, improved photosynthetic capacity, increased number of leaves, larger stem diameter and plant size.

The use of Si in agriculture has presented a reduction of insect pest and disease incidence in host plants, since that element, when absorbed, promotes deposition of silica on cell wall, making plants more resistant to fungi and insect attack (Gomes et al., 2009). This is only possible because silica associates with cell wall constituents, making it less accessible to degrading enzymes (mechanical resistance) of invaders. Si also acts against some fungal diseases in Si non-accumulating plants, as in the case of common bean. In this case, the action of this element is believed to occur not exclusively by mechanical barrier formation, but also by induction of phenol (phytoalexins) production (Yamada and Abdalla, 2006).

The importance of common bean in Brazil makes research of alternative means to provide increased productivity with decreased production cost necessary. However, studies concerning management methods that employ Si are still incipient and inconclusive (Franzote et al., 2005), especially those seeking to clarify the relation between nutrition and problems caused by pests, as well as the relation of this element to agronomic aspects of the cultivation.

Thus, use of foliar fertilization with Si is believed to provide better conditions for common bean regarding the evaluated agronomic characteristics.

Therefore, the objective of this study was to evaluate, in two sowing times, the agronomic performance of two common bean cultivars according to foliar application of different doses of potassium silicate.

MATERIALS AND METHODS

Experiments were conducted under field conditions, in the rural area of the city of Assis Chateaubriand, Paraná, Brazil. The first experiment was established in August 2014 (rainy season crop) and the second one was established in February 2015 (dry season crop), both in eutroferric Red Latosol. The area is located at coordinates: Latitude 24°17´27.40´´ S and Longitude 53°35´03.99´´ W, at an altitude of 321 m.

Climate data referring to the experimental management period were collected and provided by COAMO (Agro industrial Cooperative), Brasilândia do Sul branch, Paraná, located 10 km from the experimental area. These data were correlated with phenological stages of the crop, as shown in Figures 1 and 2.

A randomized block design was used in both experiments, in a 2 × 5 factorial design, with four replications. The first factor refers to common bean cultivars (IPR Campos gerais and IPR Tuiuiú) belonging to pinto and black bean groups, respectively.

The second factor refers to doses of a commercial potassium silicate product (0.0, 250, 500, 750 and 1000 ml ha^{-1}) reported to contain 0.9 w/v of SiO_2 (90 g/L water) and 18% K_2O in its formulation, according to manufacturer's information. The product was diluted in humic acid. Experimental plots were 10 m long by 7.74 m wide, totaling 18 lines and 77.4 m^2 total area.

Prior to the first experiment installation, soil was sampled to a depth of 0 to 20 cm, presenting the following results: P = 6.30 mg dm^{-3} (Mehlish-1); pH ($CaCl_2$) = 4.80; H + Al = 3.18 cmol$_c$ dm^{-3}; Al^{3+} = 0.00 cmol$_c$ dm^{-3}; Mg^{2+} = 1.25 cmol$_c$ dm^{-3}; Ca^{2+} = 4.05 cmol$_c$ dm^{-3}; K^+ = 0.16 cmol$_c$ dm^{-3}; Mn = 146.49 mg dm^{-3}; Fe = 55.72 mg dm^{-3}; Cu = 7.62 mg dm^{-3}; Zn = 3.28 mg dm^{-3}; Si = 19.6 mg dm^{-3}; V% = 63.19; Clay = 73.5%; Coarse sand = 2.3%; Fine sand = 3.2%; Gravel = 0.0%; Silt = 21.0%; Textural class = Clayey soil.

Liming was not performed in both experiments conducted in order to avoid favoring of one experiment over another. This is because when this procedure is performed to increase soil pH, hydroxyl formation occurs in the corrected soil profile (however, a time interval is needed for such effect to occur). Thus, it could lead to an advantage for the second experiment conducted over the first one, with regard to productivity increase and other agronomic characteristics evaluated in this study.

Fertilization employed was based on soil analysis, abiding by recommendations of IAPAR (2003) for common bean culture. At the time of planting, 300 kg ha^{-1} of 16-16-16 fertilizer was

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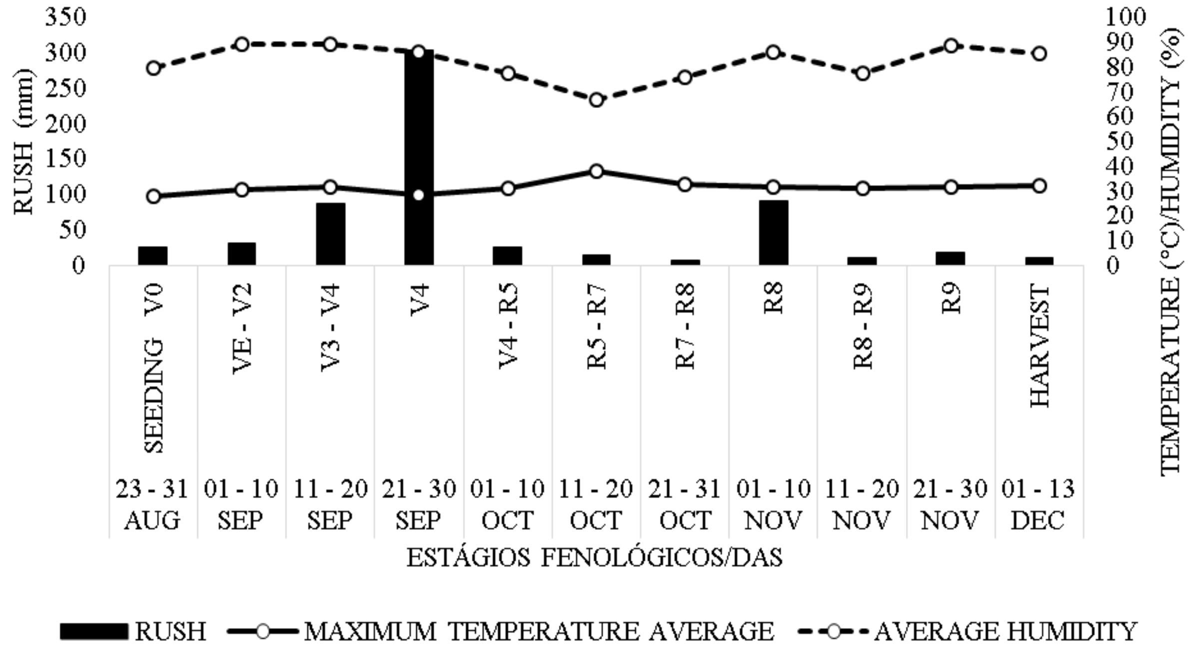

Figure 1. Maximum temperature, precipitation, relative humidity during the experiment, rainy season crop - 2014. Assis Chateaubriand, Paraná, Brazil. Source: COAMO, Brasilândia do sul.

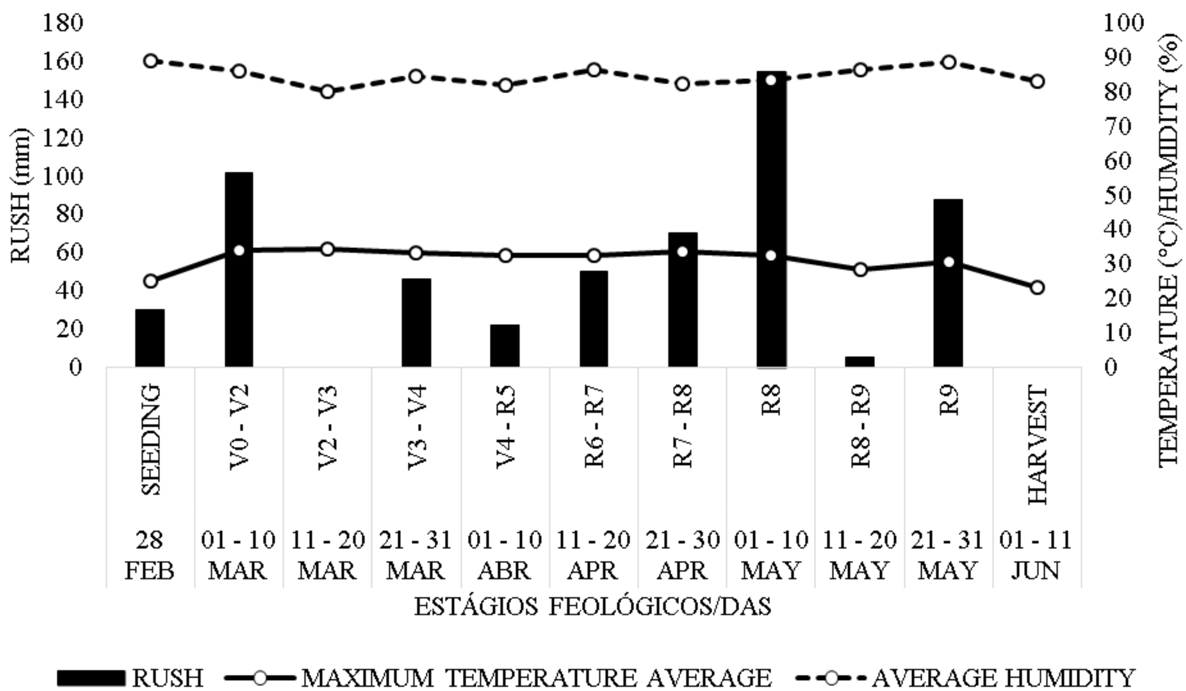

Figure 2 Maximum temperature, precipitation, relative humidity during the experiment, dry season crop - 2014. Assis Chateaubriand, Paraná, Brazil. Source: COAMO, Brasilândia do sul.

incorporated in the sowing groove. At the V4/R5 phenological stage, nitrogen top dressing was performed by using urea (45% N) as N source at a dose of 64 kg ha^{-1}.

Row spacing used was 0.43 m, with 12 seeds per linear meter. Seeds were treated with fungicide (Carbendazim) and insecticide (Imidacloprid + Tiodicarb) according to the dose recommended by

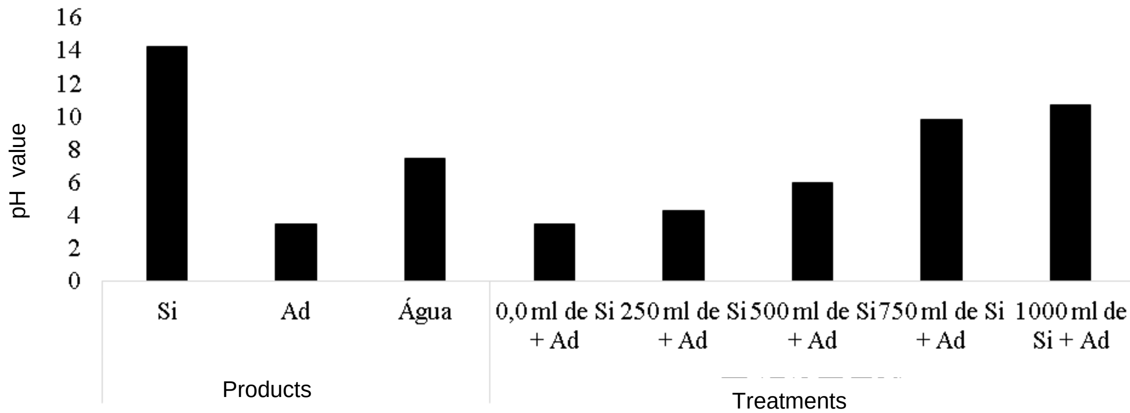

Figure 3. The pH of the products and doses used: potassium silicate (Si), spray adjuvant (Ad), water and spray mixes (treatments).

the manufacturer.

Sowings were performed on August 23 (rainy season crop) and on February 28 (dry season crop). Harvests were performed on December 13 and on June 11, respectively. During the crop development, weed control through manual weed and/or through herbicide Fomesafem + Fluazifop-p-butyl use (according to the dose recommended by the manufacturer) were adopted in both experiments when necessary.

For insect pest control, insecticides Imidacloprid + beta-Cyfluthrin and Teflubenzuron were used in the experiment conducted during rainy season crop, whereas Imidacloprid + beta-Cyfluthrin, Teflubenzuron, Spiromesifen and Methomyl were used in the experiment conducted during dry season crop. Regarding disease control, fungicides Carbendazim; pyraclostrobin + metconazole and copper hydroxide were used in the experiment conducted during rainy season crop, whereas only copper hydroxide was used in the experiment conducted during dry season crop. Doses were used according to recommendation of each manufacturer.

An adjuvant was added to the spray mix preparation, in order to provide better abrasive effect between the mix of different treatments and potassium silicate solution on bean leaves. The pH of the products used and of the treatments can be checked in Figure 3. The adjuvant added to the spray mix is composed of a blend of Phosphatidylcholine (Soy lecithin) and Acid Propionic, which improves foliar absorption of nutrients by plants.

Potassium silicate applications were divided into fortnightly applications, from phenological stage V3 to R8. The same quantity of potassium silicate established for each treatment was used at the different application times. In both experiments, the treatments evaluated were applied 4 times.

For application, an electric knapsack sprayer was used with fixed working pressure at 45 Psi, aided by a spray bar with 4 flat fan nozzles spaced 50 cm apart, with spray volume of 186 L ha^{-1}. A digital pH meter was used to determine the spray mix pH of each treatment. The device was calibrated with pH 4 and 7 buffers for subsequent measurements. The pH values of the products used (potassium silicate and spray adjuvant) were provided by the manufacturers.

Two central 8-m long planting rows from plots were considered as floor area (that is, 1 m between plots of the same block was disregarded), totaling 6.88 m², from which 10 plants were chosen randomly to determine agronomic characteristics (plant height, number of pods per plant and dry matter weight of the aerial part).

Ten central 8-m long planting rows from plots were considered as A graduated tape measure was used to determine plant height (PH) by measuring plant length from its base (stem above soil surface) to the end of the branch.

As for dry matter weight of the aerial part (DWAP), plants from floor area were placed in Kraft paper bag and dried to constant weight in a forced air circulation oven (62°C). The material was removed from oven. Its weight was immediately determined by using an analytical balance and subsequently extrapolated in kg per hectare. Plants from floor area were collected to determine grain yield and humidity was corrected to 13%.

Data were submitted to variance analysis by using Sisvar 5.1. statistical software.

RESULTS AND DISCUSSION

Variance analysis results regarding agronomic characteristics evaluated for the experiments conducted (rainy season crop and dry season crop) are shown in Tables 1 and 3. Mean values obtained for the evaluated characteristics are shown in Tables 2 and 4, for both crops.

As observed in Table 1 regarding the experiment conducted in rainy season crop (2014), there are statistical differences between cultivars evaluated by F-test (p<0,05) for agronomic characteristics: plant height (PH), thousand seed weight (TSW) and grain yield (GY).

IPR Campos Gerais was found to reach 73.95 cm average plant height (PH), whereas IPR Tuiuiú reached 67.88 cm average plant height. Regarding dry matter weight of the aerial part (DWAP), there was no significant difference (P>0.05) between cultivars. The mean values obtained for IPR Campos Gerais and IPR Tuiuiú cultivars were 13820.41 and 13056.85 kg ha^{-1}, respectively. Regarding thousand seed weight (TSW), there was statistical difference (P<0.05) between the means compared. IPR Campos Gerais cultivar reached an average thousand seed weight of 247.30 g, whereas IPR Tuiuiú cultivar reached an average of 167.85 g. As for grain yield, there was statistical difference (P<0.05) between the means obtained. IPR Campos Gerais

Table 1. Variance analysis of agronomic characteristics summary: plant height (PH); dry matter weight of the aerial part (DWAP); number of pods per plant (NPP); thousand seed weight (TSW) and grain yield (GY). Rainy season crop – 2014. Assis Chateaubriand, Paraná, Brazil.

Sources of variation	Rainy season crop – 2014					
	GL	PH	DWAP	NPP	TSW	GY
Cultivar	1	368.45*	349.22[Ns]	0.064[Ns]	63123.03*	222689.96*
Block	3	217.38	3086.74	16.35	2350.76	110912.91
Doses	4	29.36[Ns]	176.94[Ns]	0.11[Ns]	173.35[Ns]	10316.07[Ns]
Cultivar x Doses	4	33.10[Ns]	415.38[Ns]	1.90[Ns]	71.15[Ns]	747.21[Ns]
Error	27	67.28	489.26	2.20	511.57	11859.10
C.V. (%)	-	11.12	21.27	20.21	10.90	25.01

[Ns]Not significant, *Significant at the 0.05 significance level (F-test).

Table 2. Mean values obtained for the evaluated characteristics: plant height (PH); dry matter weight of the aerial part (DWAP); number of pods per plant; (NPP); thousand seed weight (TSW) and grain yield (GY). Rainy season crop – 2014. Assis Chateaubriand, Paraná, Brazil.

Cultivar	Mean values				
	pH (cm)	DWAP (kg ha^{-1})	NPP (Unit)	TSW (g)	GY (kg ha^{-1})
IPR Campos Gerais	73.95[a]	13820.41[a]	7.30[a]	247.30[a]	510.02[a]
IPR Tuiuiú	67.88[b]	13056.85[a]	7.38[a]	167.85[b]	360.79[b]
CV (%)	11.12	21.27	20.21	10.90	25.01

Means followed by the same letter are not significantly different by Tukey’s test at the 5% probability level.

Table 3. Variance analysis of agronomic characteristics summary: plant height (PH); dry matter weight of the aerial part (DWAP); number of pods per plant; (NPP); thousand seed weight (TSW) and grain yield (GY). Dry season crop – 2015. Assis Chateaubriand, Paraná, Brazil.

Sources of variation	GL	PH	DWAP	NPP	TSW	GY
Cultivar	1	1550.03*	6630.63*	0.63[Ns]	140.63[Ns]	916393.98*
Block	3	16.03	5662.29	12.29	803.16	375252.51
Doses	4	103.54[Ns]	1478.75[Ns]	8.59[Ns]	223.63[Ns]	20765.57[Ns]
Cultivar x Doses	4	24.71[Ns]	1080.63[Ns]	4.44[Ns]	255.75[Ns]	34571.33[Ns]
Error	27	39.84	1251.64	3.87	130.10	49199.21
C.V. (%)	-	7.92	17.90	13.77	6.01	19.44

[Ns]Not significant, *Significant at the 0.05 significance level (F-test).

Table 4. Mean values obtained for the evaluated characteristics: plant height (PH); dry matter weight of the aerial part (DWAP); number of pods per plant; (NPP); thousand seed weight (TSW) and grain yield (GY). Dry season crop- 2015. Assis Chateaubriand, Paraná, Brazil.

Cultivar	Mean values				
	pH (cm)	DWAP (kg ha^{-1})	NPP (Unit)	TSW (g)	GY (kg ha^{-1})
IPR Campos Gerais	85.90[a]	23.869.51[b]	14.40[a]	191.75[a]	989.43[b]
IPR Tuiuiú	73.45[b]	27.196.38[a]	14.15[a]	188.00[a]	1.292.15[a]
CV (%)	7.92	17.90	13.77	6.01	19.44

Means followed by the same letter are not significantly different by Tukey's test at the 5% probability.

produced 510.02 kg ha^{-1}, whereas IPR Tuiuiú cultivar produced 360.79 kg ha^{-1} (Table 2).

For the experiment conducted in dry season crop, significant differences were observed in cultivars evaluated by F-test (P<0.05) regarding plant height (PH), dry matter weight of the aerial part (DWAP) and grain yield (GY) (Table 3).

The average plant height (PH) presented was 85.90 for IPR Campos Gerais cultivar, and 73.45 for IPR Tuiuiú. Regarding dry matter weight of the aerial part (DWAP), there was statistical difference between cultivars (P<0.05). IPR Tuiuiú presented 23869.51 kg ha^{-1}, whereas IPR Campos Gerais cultivar presented 27196.38 kg ha^{-1}. Moreover, there was statistical difference (P<0.05) regarding grain yield, as IPR Tuiuiú reached 1292.15 kg ha^{-1} and IPR Campos Gerais reached 989.43 kg ha^{-1} (Table 4).

Differences observed at the same sowing time can probably be assigned to genetic basis of the cultivars studied, since different common bean groups are concerned. IPR Campos Gerais belongs to Pinto bean group, whereas IPR Tuiuiú cultivar belongs to Black turtle bean group. Consequently, genotypes behaved differently due to their characteristics, as observed in other studies (Coelho et al., 2010; Teixeira et al., 2010).

Thousand seed weight (TSW) is one of the main characteristics that differentiate common bean genotypes, being little influenced by environment (Ramalho et al., 1993). Thus, even under different environment conditions, it was observed that TSW of each genotype evaluated may undergo slight alterations only (Coelho et al., 2007).

However, in a study performed by Hoffmann Junior et al. (2007), the authors observed a general negative impact on thousand seed weight when common bean are exposed to high temperatures during reproductive stage, as genotypes behaved differently, presenting tolerant materials according to climatic conditions under which the study was conducted, keeping constant TSW for some evaluated materials. Similar results are observed in this study (Tables 1 and 3).

According to Coimbra et al. (1999), TSW is highly associated with grain yield. Consequently, a reduced thousand seed weight in genotype will cause significant losses in final grain yield.

According to an informative technical bulletin provided by IAPAR (2015), cultivars have an indeterminate growth habit type II, and its inflorescences arise from axillary buds. Apical bud continues to grow even in reproductive stage, forming a branch that does not exceed a few centimeters; total plant height reaches approximately 70 cm. Lateral buds are short and cultivars present a flowering period ranging from15 to 20 days, with pods maturing evenly. Plants have a life cycle of 80 to 90 days, with about 3897 kg ha^{-1} of yield potential for IPR Campos Gerais cultivar, and 3950 kg ha^{-1} for IPR Tuiuiú cultivar.

By analyzing the climatic behavior and phenological development of materials in the cultivation environment of both crops (Tables 1 and 2), differences were observed in each crop, demonstrating that environmentally adverse conditions can negatively affect common bean development, especially precipitation and temperature.

Values corresponding to productivity of both crops (Tables 2 and 4) are considered low when compared with productive potential of the materials studied. Such low productivity may be assigned to unfavorable climatic conditions for crop development, occurred during experiments conduction. During rainy season crop and dry season crop, climatic conditions presented mean values of maximum air temperature over 30°C along the entire experiment period, as observed in Tables 1 and 2, reaching nearly 40°C during rainy season crop when it was at the reproductive stage of development R7 (pod formation).

Common bean plant is susceptible to abrupt and/or extreme climatic factors, mainly temperature (below 15°C or over 27°C) and uneven precipitation. In such cases, the crop cannot complete its cycle optimally, undergoing productivity losses mainly due to flower/pod abortion, grain malformation, small size or lodging.

Still in relation to productivity loss, very high temperatures are known to cause the most harmful adverse effect for common bean flowering and fruiting, as observed in this study, and are one of the main influential factors on flower abortion, fruit setting, and final pod retention in common bean (Dickson and Boettger, 1984; Portes, 1988). High temperature is also responsible for a fewer number of seeds per pod. Air temperature adopted as optimal for a proper physiological development of plant ranges from 15 to 27°C (Bulisani et al., 1987).

According to Dickson and Petzoldt (1989), common bean crop can be harmed by the occurrence of high air temperatures at the different phenological stages of plant development. It is also known that the greatest damages caused by high temperatures occur at the reproductive stage of development (R5 and R6). Air temperature conditions ranging between 30 and 40°C are the cause for higher flower and floral bud abortion rate, reducing bean plant yield. In this study, these relations were observed more clearly for rainy season crop (Dickson and Petzoldt, 1989).

In this context, according to Gonçalves et al. (1997), temperatures over 30°C can promote sterilization of pollen grain and increase ethylene production in the plant, factors related to blossom drop and graining deficiency.

For Maluf and Caiaffo (1999), several common bean reproductive stages are susceptible to high temperature, including floral bud formation (R5), pollen formation, fertilization, and pods and seeds formation (R7) The author reports damages after anthesis, as flower abscission and low fruit setting of pods and seeds (due to lack of pollination or fertilization) resulting from exposure to 38°C average temperature during the first days of flowering, are responsible for productivity losses of about 67%.

Another yield limiting factor is precipitation, which, as well as air temperature, was unfavorable for plant development during the experiments conducted, affecting grain yield (Tables 1 and 2). During rainy season crop rainfall distribution was irregular and insufficient, hampering crop development.

Despite a better rainfall distribution during dry season crop, from emergence to filling of pods, the quantity of precipitation was also insufficient to meet crop needs. According to studies conducted by Back (2001), common bean requires about 100 mm evenly distributed rainfalls monthly to fulfill its cycle with no restrictions. Though, according to studies conducted by Maluf and Caiaffo (1999), common bean requires 300 to 400 mm evenly distributed precipitation between sowing time and physiological maturity, to fulfill its cycle with no restrictions. That is because this species is not very tolerant to water deficiency mainly due to its shallow root system, which results in low recovery capacity after severe water deficit in the soil (Guimarães et al., 1996).

During reproductive stages of growth R5 to R9, mainly between R5 and R7, common bean is highly susceptible to water deficiency in the soil (Fageria et al., 1991), because in such stages plant is at its maximum metabolical potential to form flower buds and, after anthesis, to develop pods and grains. The same phenomenon was observed in a study conducted by Matzenauer et al. (1991). According to the authors, the critical period for common bean regarding water deficiency is the sub-period from beginning of flowering (R5) to beginning of grain filling (R8).

When water stress occurs in the reproductive stage, yield reduction is associated with decreased leaf area and number of pods per plant (Acosta-Gallegos and Shibata, 1989). According to Gomes et al. (2000), yield decrease is more than 50% when water stress occurs between the 5 and 10th day before anthesis. Productivity reductions are proportional to the number of days common bean is subjected to drought (Stone et al., 1988), as observed in this study.

No significant effect was observed regarding potassium silicate application for the evaluated characteristics (Tables 1 and 3). It probably happened because the experiment was conducted in a clayey soil (73.5% clay). According to Camargo (2007), soluble Si content is higher in that type of soil. Eutroferric Red Latosol is a very weathered type of soil, with higher quantity of clay. In the experimental area, the quantity of soluble Si measured in the soil was 19.6 mg dm^3, value considered to be very high. This is the reason why Si would hardly demonstrate its effects with foliar fertilization of crop, even more by the fact that common bean is a silicon non-accumulating plant.

When Si is found in the liquid phase of the soil as a monocyclic acid, it is absorbed by plant roots through passive transport, which occurs when soil nutrient moves to the root surface with the concentration gradient (nutrient moves from the higher concentration area, rhizosphere, to a lower concentration area, root), requiring no expenditure of metabolic energy by the plant (Taiz and Zeiger, 2013).

Plants can absorb mineral more easily through root system, since they have a greater quantity of membrane transport proteins by which molecules and ions can diffuse through membrane, making a lower expenditure of metabolic energy possible (Taiz and Zeiger, 2013).

This way, as plants absorb Si through roots in order to meet their needs for this element, foliar absorption is not justifiable. Furthermore, since root system presents larger specific surface area (contact of the element with the plant tissue) and larger quantity of transport proteins, the amount of Si it absorbs will always be greater than the quantity absorbed by the aerial part. However, the precise way Si is absorbed is still unknown (Takahashi et al., 1990).

Nonetheless, as soluble Si concentration in this soil is very high, this element was probably absorbed by the roots and met plant needs. Therefore, regarding the potassium silicate doses studied and the interaction between these doses and the cultivars, foliar fertilization with potassium silicate did not provide significant results ($P>0.05$) for such evaluated characteristics. It is important to emphasize that Latosols contain a large quantity of kaolinite, which still undergoes weathering action, and consequently releases soluble Si to soil by the action of the weather (Lima, 2001).

Moreover, common bean is a dicotyledon plant considered to be silicon non-accumulating. This legume is classified as a plant able to accumulate under 2% SiO_2 in dry matter, quantity considered insignificant to improve and 3 formerly presented (Takahashi, 2002; Hodson et al., 2005).

For future studies, it is important to explore results for potassium silicate application in plants grown in soils with different clay percentages and soluble Si, and in Si-accumulating plants.

Conclusions

Foliar fertilization with potassium silicate did not influence the agronomic characteristics of common bean cultivars, in both evaluated crops.

IPR Campos Gerais cultivar presented greater plant height, thousand grain weight and grain yield for rainy season crop when compared with IPR Tuiuiú cultivar, which in turn presented higher grain yield in dry weather crop.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

Andrade MJB, Oliveira DP, Figueiredo MA, Martins FAD (2015). Exigências Edafoclimáticas. In: Carffneiro JES, Paula Júnior J, Borém A (Ed.). Feijão: do plantio à colheita. Viçosa: Ed. UFV. pp. 67-95.

Back AJ (2001). Necessidade de irrigação da cultura de feijão no sul do estado de Santa Catarina. Revista Tecnologia e Ambiente, Criciúma. p.35-44, janeiro/junho

Bulisani EA, Almeida LDA, Roston AJ (1987). A cultura do feijoeiro no Estado de São Paulo. In: BULISANI, E. A. Feijão: fatores de produção e qualidade. Campinas: Fundação Cargill pp. 29-88.

Camargo MS, Pereira HS, Korndorfe GE, Reis GE (2007). Soil reaction and absorption of silicon by rice. Scientia Agricola, Piracicaba, p. 176-180.

Chérif M, Benhamou N, Menzies JG, Bélanger RR (1992). Silicon induced resistance in cucumber plants against Pythium ultimum. Physiol. Mol. Plant Pathol. 41(6):411-425.

Coelho CMM, Mota MR, Souza CA, Miguellutti DJ (2010). Potencial fisiológico em sementes de cultivares de feijão crioulo (*Phaseolus vulgaris L.).* Rev. Bras. Sementes, pp. 097-105.

Coelho CMM, Coimbra JLM, Souza CA, Bogo A, Guidolin AF (2007). Diversidade genética em acessos de feijão (*Phaseolus vulgaris* L.). Cienc. Rural. pp. 1241-1247.

Coimbra JLM, Guidolin AF, de Carvalho FIF, Coimbra SMM, Hemp S (1999). Reflexos da interação genótipo X ambiente e suas implicações nos ganhos de seleção em genótipos de feijão (*Phaseolus vulgaris* L.). Ciênc. Rural 29(3):433-439.

De Oliveira E (2003). Sugestao de adubacao e calagem para culturas de interesse economico no Estado do Parana (No. 04642).

Dickson MH, Petzold R (1989). Heat tolerance and pod set in green beans. J. Am. Soc. Horticul. Sci. Alexandria 114(5):833-836.

Dickson MK, Boettger MA (1984). Effect of high and low temperatures on pollen germination and seed set in snap beans. J. Am. Soc. Horticul. Sci. Alexandria – EGY. 109(3)372-374.

Fageria NK, Baligar VC, Jones CA (1991). Common bean and cowpea. In: Growth and mineral of field crops. New York: M. Dekker, p. 280-318.

Franzote BP, Silveira MJBDA, Maria N, Vieira B, Silva VMPE, De Carvalho JG (2005). Aplicação foliar de silício em feijoeiro comum. In: Congresso Nacional De Pesquisas De Feijão 8:957-960).

Gallegos JAA, Shibata JK (1989). Effect of water stress on growth and yield of indeterminate dry-bean (Phaseolus vulgaris) cultivars. Field Crops Res. 20(2):81-93.

Ghanmi D, McNally DJ, Benhamou N, Menzies JG, Bélanger RR (2004). Powdery mildew of Arabidopsis thaliana: a pathosystem for exploring the role of silicon in plant–microbe interactions. Physiol. Mol. Plant Pathol. 64(4):189-199.

Gomes FB, Moraes JC, Neri DKP (2009). Adubação com silício como fator de resistência a insetos-praga e promotor de produtividade em cultura de batata inglesa em sistema orgânico. Ciênc. Agrotec. Lavras 33(1):18-23.

Gomes AA, Araújo AP, Rossiello RO, Pimentel C. (2000). Acumulação de biomassa, características fenológicas e rendimento de grãos de cultivares de feijoeiro irrigado e sob sequeiro. Pesqui. Agropecu. Bras. 35(10).

Gomes FB, Moraes JCD, Santos CDD, Goussain MM (2005). Resistance induction in wheat plants by silicon and aphids. Sci. Agric. 62(6):547-551.

Gonçalves SL, Wrege MS, Caramori PH. (1997). Probabilidade de ocorrência de temperaturas superiores a 30°C no florescimento do feijoeiro (*Phaseolus vulgaris*), cultivado nas safras das águas no Estado do Paraná. Rev. Bras. *Agrometeorologia, Santa Maria*, 5(1):99-107.

Goussain MM, Prado E, Moraes JC (2005). Effect of silicon applied to wheat plants on the biology and probing behaviour of the greenbug *Schizaphis graminum* (Rondani (*Hemiptera: Aphididae*). Neotrop. Entomol. 34:807-813.

Guimarães CM, Stone LF, Brunini O (1996). Adaptação do feijoeiro (*Phaseolus vulgaris* L.) à seca. II: *produtividade e componentes agronômicos*. Pesqui. Agropecu. Bras. Bras. 31(7):481-488.

Hodson MJ, White PJ, Mead A, Broadley MR (2005). Phylogenetic variation in the silicon composition of plants. Ann. Bot. 96(6)1027-1046.

Hoffmann Jr L, Ribeiro DN, Rosa SS, Jost E, Poersch NL, Medeiros SLP (2007). Resposta de cultivares de feijão à alta temperatura do ar no período reprodutivo. Ciência Rural 37(6):1543-1548.

IAPAR (2015). Principais características das cultivares de feijão com sementes disponíveis no mercado. Disponível em: http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=1363 . Acesso em 01 de junho de.

Lima HN (2001). Gênese, química, mineralogia e micromorfologia de solos da Amazônia Ocidental. Viçosa, Universidade Federal de Viçosa, f. 176. (Tese de Doutorado).

Ma JF, Takahashi E (2002). Soil, fertilizer, and plant silicon research in Japan. 1 ed. Amsterdam: El sevier Science, 503 p.

Malavolta E (2006). Manual de nutrição mineral de plantas. São Paulo: Editora Ceres, 443 p.

Maluf JRT, Caiaffo MRR (1999). Zoneamento agroclimático da cultura de feijão no Estado do Rio Grande do Sul: recomendação de períodos favoráveis de semeadura por região agroecológica. In: Reunião Nacional De Pesquisa De Feijão, 6., Salvador. *Resumos... Goiânia: Embrapa Arroz e Feijão,* pp. 455-458.

Marschner H (1995). Mineral nutrition of higher plants. 2. ed. London: Academic Press, 889 p.

Matzenauer R, Bueno AC, Maluf JRT (1991). Evapotranspiração máxima e coeficiente de cultura para o feijão. In: Congresso Brasileiro De Agrometeorologia, 7. Resumos... Viçosa: Soc. Bras. Agrometeorol. pp. 235-236.

Menzies JG, Ehret DM, Glass ADM, Helmer T, Koch S, Seywerd F (1991). The effects of soluble silicon on the parasitic fitness of Sphaerotheca fuliginea (Shlect. Fr.) Poll. on Cucumis sativus L. Phytopathology 81:84-88.

Moura AD, Brito LM (2015). Aspéctos Socioeconômicos. In: Carneiro JES, Paula JJ, Borém A (Ed.). In: Feijão: do plantio à colheita. Viçosa: Ed. UFV. pp. 19-21.

Portes TA (1988). Ecofisiologia. In: Zimmermann MJO, Rocha M, YAMADA T (ed.). Cultura do feijoeiro comum no Brasil. *Piracicaba – SP: Potafos,.* pp. 125-126.

Ramalho MAP, Santos JB, Zimmermann MJO (1993). Genética quantitativa de plantas autógamas: aplicações ao melhoramento do feijoeiro. Goiânia: UFG, 271 p.

Samuels AL, Glass ADM, Ehret DL, Menzies JG (1991). Distribuition of silicon in cucumber leaves during infection by powdery mildew fungus (*Sphaerotheca fuliginea*). Can. J. Bot. 69:140-146.

Stone LF, Portes TA, Moreira JAA (1988) Efeito da tensão da água do solo sobre a produtividade e crescimento do feijoeiro II: crescimento. Pesqui. Agropecu. Bras., Brasília, 12(5):503-510.

Taiz L, Zeiger E (2013). Fisiologia vegetal. 5. ed. *Porto Alegre*: Artmed, pp. 139-918.

Takahashi E, Ma JF, Miyake Y (1990). The possibility of silicon as an essential element for higher plants. Comments on Agricultural and Food Chemistry, 2(2):99-102.

Teixeira IR, Silva GC, Oliveira JP, Silva AG, Pelá A (2010). Desempenho agronômico e qualidade de sementes de cultivares de feijão-caupi na região do cerrado. Rev. Ciênc. Agronômica, 41(1):300-307.

Yamada T, Abdalla SRS (2006). Manejo sustentável na agricultura. *Informações Agronômicas, Piracicaba,* 116:1-32.

Yoshida AS, Ohnishi Y, Kitagishi K (1962). Histochemistry of silicon in rice plant. Soil Sci. Plant Nutr. 8:107-111.