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## Growth and production of common bean fertilized with biochar

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**ABSTRACT:** Production of biochar from organic wastes promises to be an interesting source of plant nutrients, thus reducing pressure on natural resources. To assess the effect of biochar prepared from wastes filtration materials on the growth and production of common bean (*Phaseolus vulgaris* L.), three simultaneous greenhouse experiments were conducted with three different biochar from organic wastes (rice husk, sawdust, and sorghum silage) using as filtration material for swine biofertilizer. In each experiment the treatments consisted of the addition of five different biochar concentrations (0%, 2.5%, 5%, 7.5%, and 10% v/v), arranged in a completely random design, with four repetitions. Application of biochar increased the root dry mass, shoot dry mass, grain dry mass, number of pods and number of grains. These results indicated that biochar contributed significantly to the growth and production of common bean plants.

**Key words:** agricultural wastes, alternative source of nutrients, *Phaseolus vulgaris* L.

## Crescimento e produção de feijoeiro adubado com biocarvão

**RESUMO:** A produção de biochar a partir de resíduos orgânicos pode ser uma estratégia agrônômica interessante como fonte de nutrientes para as plantas, diminuindo assim, a pressão sobre os recursos naturais. Com o objetivo de avaliar o efeito de biocarvões, produzidos de materiais filtrantes descartados, no crescimento e produção de feijão (*Phaseolus vulgaris* L.), conduziram-se simultaneamente três experimentos em casa de vegetação. Cada um dos experimentos foi representado pela aplicação de um biochar, os quais foram produzidos a partir de resíduos orgânicos de casca de arroz, serragem e restos de silagem de sorgo, utilizados como material filtrante para o biofertilizante suíno; e os tratamentos avaliados consistiram na adição de cinco níveis de biocarvão, isto é, 0, 2,5%, 5%, 7,5% e 10% v/v. Nos três experimentos a aplicação de biochar aumentou a massa seca da raiz, massa seca da parte aérea, massa seca de grãos, número de vagens e número de grãos. Esses resultados indicam que os biochars contribuíram significativamente para o crescimento e produção do feijoeiro.

**Palavras-chave:** resíduos agrícolas, fonte alternativa de nutrientes, *Phaseolus vulgaris* L.

## INTRODUCTION

The use of organic wastes as a filtering material is an efficient and low cost option for the primary treatment of wastewater. However, as the filter medium retains the impurities of the liquid, the filtration rate is reduced, making it necessary to replace the filter material at defined intervals of time. Substitutions lead to the formation of large waste streams, which can be used directly as organic fertilizers. Alternatively, this residue can undergo a pyrolysis process under controlled conditions of

temperature and oxygen, producing a material called biochar (MUKHERJEE & LAL, 2016).

Biochar is a solid, carbon-rich material obtained from the thermochemical transformation of biomass under a low oxygen atmosphere. It is usually added to the soil in order to improve its chemical, physical and biological properties (KOOKANA et al., 2011).

Production and use of biochar is interesting in several aspects. Firstly, the production of biochar allows the recycling of large quantities of agricultural wastes (ABDELHAFEZ et al., 2014), reducing

the contamination associated with the disposal to the environment (AHMAD et al., 2014; GWENZI et al., 2015). Second, unlike the organic matter *in nature* which tends to decompose rapidly, biochar is considered a stock of stable carbon and slow degradation, which makes an efficient alternative to increase storage and sequestration in the soil (JOSKO et al., 2013) and to reduce emissions of greenhouse gases (GWENZI et al., 2016). Finally, biochar can act as a soil conditioner (ALBUQUERQUE et al., 2014). In this way, the application of biochar to the soil increases its water retention, pH, concentration of available nutrients, cation exchange capacity and reduction of soil bulk density and; improves the associations of plants with mycorrhizal fungi, reflecting the higher absorption of phosphorus by plants (HAMMER et al., 2014).

Concerning the effect of biochar on agricultural crops production, the current results are not conclusive and data on the use of field biochar in large areas are lacking (MUKHERJEE & LAL, 2016). In a review using approximately 50 published works, through a quantitative analysis of the effects of applying biochar to soil on crop yield, JEFFERY et al. (2011) observed that, on the whole, the use of biochar increased by more than 10% crops productivity. Conversely, there is a great variability of the responses of the cultures to the application of biochar due to differences in the soil properties, environmental conditions, as well as in the type of organic materials and temperature conditions in the pyrolysis process, resulting in products with quite different properties.

The pyrolysis temperature in conjunction with the presence of oxygen influences the pH of the biochar through the production of ash (REHRAH et al., 2014). According to the authors, the higher the temperature the higher the pH of biochar. Consequently, the biochar pH influences aluminum toxicity and the availability of nutrients from the soil to the plants. Therefore it is necessary to further investigate the effects of biochar on agricultural production under specific conditions, such as available raw materials and pyrolysis conditions, climatic conditions, soil type and crop to be cultivated.

In this way, organic waste with potential environmental pollution can be used in agriculture in the form of biochar, as in common beans (*Phaseolus vulgaris* L.) cultivation. This species is one of the most cultivated legumes in Brazil, which makes it one of the main sources of protein in the Brazilians diet.

The objective of this study was to evaluate the effects of the addition of biochar produced from

filter materials discarded from organic filters on common bean plants growth and production.

## MATERIALS AND METHODS

### *Preparation and characterization of biochars*

The biochars used in the present study were produced from material obtained from three different organic filters, used in the filtration of swine biofertilizer from an anaerobic biodigestor.

After filling filters with biofertilizer solids, the filtration media of rice husk, sawdust, and sorghum silage was removed and air-dried. These materials were then charred using a traditional carbonizer. During the charring process, the temperature varied between 385°C and 430°C and the total duration of the process varied between 2.3 and 3.2h, depending on the charred material.

Three different biochar produced from the filter residues by the pyrolysis process were designated as biochar from rice husk filter (BRHF), biochar from sawdust filter (BSF), and biochar from sorghum silage filter (BSSF), respectively. The yield of each biochar was determined using the following equation: Biochar yield = biochar mass/filtration material mass.

The biochar were ground into particles (<0.5mm) before they were applied to the soil and prior to sampling for characterization. Biochar chemical characterization (Table 1) was performed according to the official method proposed by the Ministry of Agriculture and Supply (MAPA, 2015) for organic fertilizers.

### *Greenhouse experiments*

Three experiments were carried out simultaneously in greenhouse, each experiment with the application of a type of biochar (BRHF, BSF or BSSF) to the soil, from February to April 2015. The treatments consisted of five different concentrations of biochar (0%, 2.5%, 5%, 7.5%, and 10% v/v), arranged in a completely random design, with four repetitions. Considering the density of the biochar (Table 1) and the layer of 0 to 20cm of depth of one hectare, these concentrations correspond to the soil incorporation of: 0, 18,5; 37,0; 55,5 and 74,0Mg ha<sup>-1</sup> of BRHF; 0; 25,5; 51,0; 76,5 and 102,0Mg ha<sup>-1</sup> of BSF and; 0; 27,0; 54,0; 81,0 and 108,0Mg ha<sup>-1</sup> of BSSF.

The surface layer (0 to 20cm) of an Oxisol (Typic Ustox) (Soil Survey Staff, 1998) was collected from an area of native vegetation (geographic coordinates: S 16°54'14.99" and W 43°57'41.28" and altitude of 678m), municipality of Montes Claros,

Table 1 – Characterization of biochars.

Properties	BRHF	BSF	BSSF
Yield (%)	33	45	38
Maximum temperature (°C)	430	385	385
Time to carbonization (h)	2.3	3.0	3.2
pH	6.8	7.1	7.2
Electrical conductivity (mS cm <sup>-1</sup> )	121.8	69.8	97
Density (kg m <sup>-3</sup> )	370	510	540
Ashes (%)	29	15	40
Organic carbon (g kg <sup>-1</sup> )	14.4	430.4	332.4
N total (g kg <sup>-1</sup> )	16.5	12.4	22.8
P (g kg <sup>-1</sup> )	34	16.7	29.6
K (g kg <sup>-1</sup> )	6.7	3.5	4.75
Ca (g kg <sup>-1</sup> )	27.3	17.8	24.44
Mg (g kg <sup>-1</sup> )	8	3.9	7.1
S (g kg <sup>-1</sup> )	2	1.3	1.5

BRHF = Biochar from rice husk filter; BSF = Biochar from sawdust filter; BSSF = Biochar from sorghum silage filter.

Minas Gerais State. Physical and chemical soil properties were determined according to CLAESSEN (1997): sand = 780g kg<sup>-1</sup>; silt = 100g kg<sup>-1</sup>; clay = 120g kg<sup>-1</sup>; pH (H<sub>2</sub>O) = 5.2; available phosphorus (resin method) = 18.01mg dm<sup>-3</sup>; potassium = 0.89mmol<sub>c</sub> dm<sup>-3</sup>; calcium = 5.0mmol<sub>c</sub> dm<sup>-3</sup>; magnesium = 2.0mmol<sub>c</sub> dm<sup>-3</sup>; aluminum = 2.4mmol<sub>c</sub> dm<sup>-3</sup>; base saturation = 24%; effective cation exchange capacity pH 7.0 = 32.5mmol<sub>c</sub> dm<sup>-3</sup>; soil organic carbon = 11.6g kg<sup>-1</sup>, Total nitrogen = 0,26g kg<sup>-1</sup>.

The soil was sifted (<4mm) and placed in 4L plastic pots. Soil in each pot was homogenized with 5g of simple superphosphate (22% of P<sub>2</sub>O<sub>5</sub>). Ten bean seeds (*Phaseolus vulgaris* L. cultivar 'BRSMG Talismã') were sown in each pot. Thinning was performed after seedling emergence, and two plants were kept per pot. The humidity of the soil in each pot was maintained in field capacity, at 60-70% of maximum water holding capacity, by weighing the pots daily and adding distilled water as required.

Four fertilizations were performed during the experimental period at 14, 21, 28, and 35 days after planting. On the two first fertilizations, each pot received 240mg dm<sup>-3</sup> of MgNO<sub>3</sub> and 250mg dm<sup>-3</sup> of KNO<sub>3</sub>. On the last two fertilizations, 100mg dm<sup>-3</sup> of urea was applied per pot, defined according to the development of the plants. These fertilizations were necessary due to the appearance of visual symptoms of nutritional deficiencies of nitrogen, magnesium and potassium in treatments with concentrations 0, and 2,5% of biochar.

#### Experiment assessment

At the time of flowering of the plants, leaves were sampled for determinations of nutrient concentrations according to the method described by MAATHUIS (2013). In the physiological maturation of the common bean plants, 2 months after sowing, the bean pods and grains were collected and dried in a forced-air oven at 60°C, until a steady mass was reached, to determine the pods and grain number and dry mass. The plants were sectioned at the height of the colon, and the aerial part was washed and dried in a forced air circulation oven at 60°C until constant mass. The soil was then removed from each vase and the roots separated by washing in running water over a 1.0mm mesh screen. Later roots were dried in a forced circulation oven at 60°C until constant mass, in order to define the root dry mass. For each experiment, the data were submitted to analysis of variance and, when significant by the F test at 5% significance, regression equations were adjusted for the variables studied as a function of the respective biochar levels.

## RESULTS AND DISCUSSION

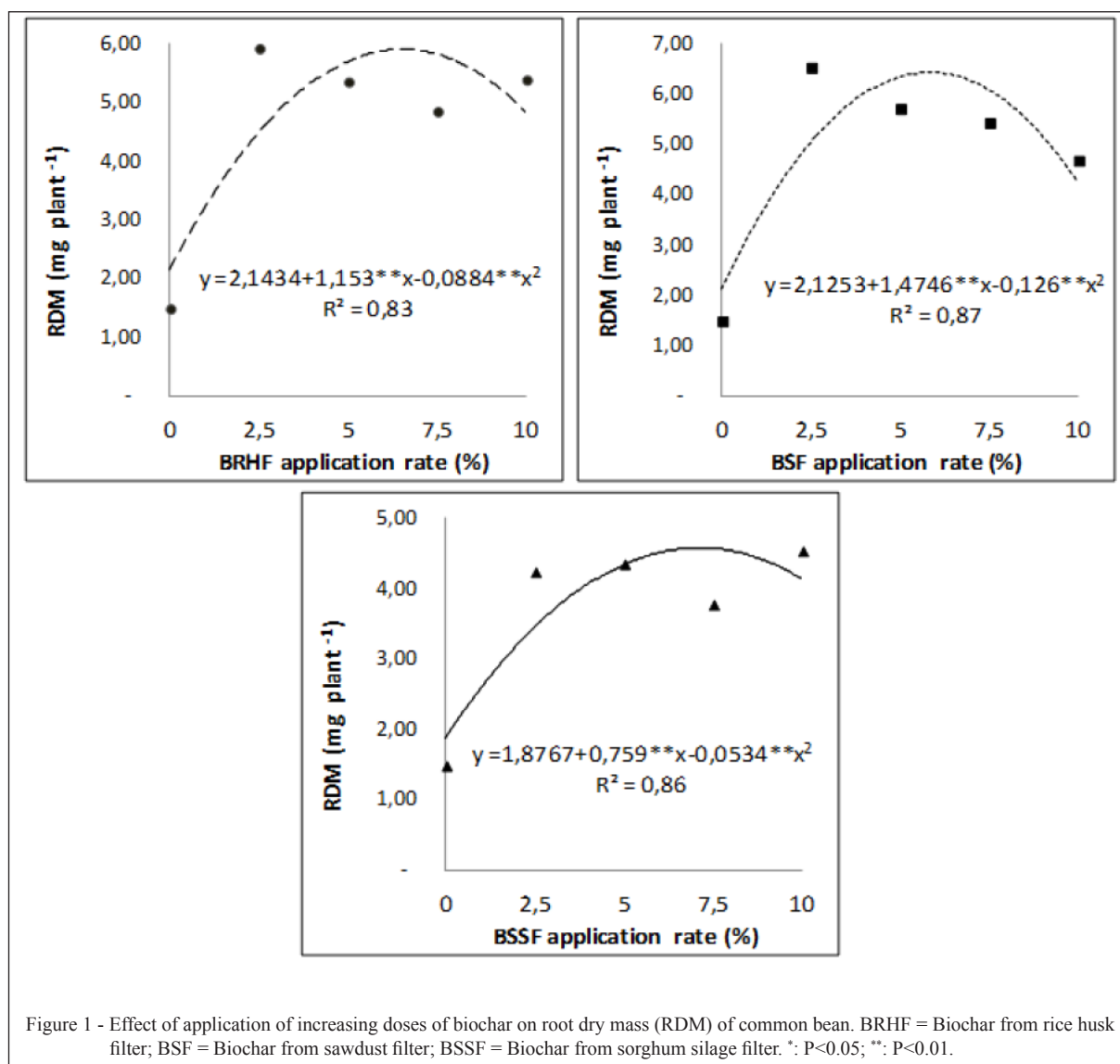
In all three experiments there was a significant effect of the different types of biochar on the growth and development of common bean plants. Addition of biochar to the soil influenced the root growth of plants. The doses of 6.52% of BRHF, 5.84% of BSF and 7.11% of BSSF provided maximum values

in root dry mass (RDM), which represented increases of 175, 202 and 143% respectively, in relation to the control treatment (Figure 1).

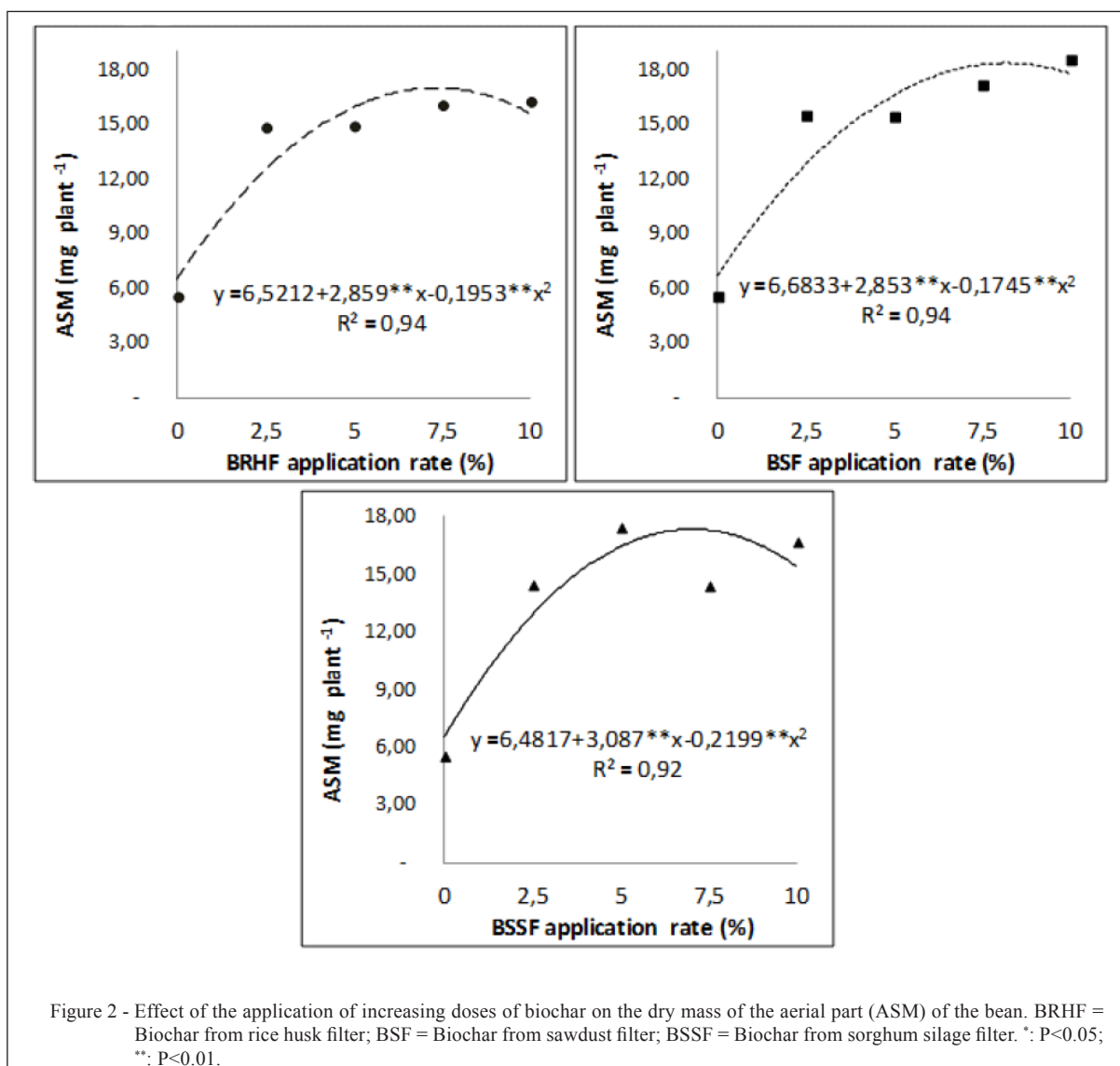
These results may be justified by improved soil quality by biochar. Several authors reported that the greatest growth and productivity of crops in soils fertilized with biochar are due to the improvements of the soil chemical, physical and biological properties. In addition to being a source of nutrients, biochar can raise soil pH, contributing to the decrease of soil acidity and aluminum toxicity (GWENZI et al., 2016), and increase of Cation Exchange Capacity and nutrient availability, mainly phosphorus that has strong interactions in acidic soils (ALBUQUERQUE

et al., 2014; YUAN & XU, 2012). In the physical properties, biochar improves soil structure and water retention (OLMO et al., 2016), while the improvement in biological properties favors plant-microorganism interactions, thus increasing water and nutrient uptake by plants (HAMMER et al., 2014; JOSKO et al., 2013). Improvements of these properties are very important for acid and poor soils from tropical regions such as those used in the present study.

In the three experiments, aerial shoot mass (ASM) presented a quadratic response to biochar doses (Figure 2). The maximum doses were 7.32% BRHF, 8.17% BSF and 7.02% BSSF, and respective ASM reached were of 16.98, 18.34 and 17.32g per plant.







The effect of biochar on the dry mass of the aerial part of the plants has been reported by several researchers (GLASER et al., 2001; RONDON et al., 2007, ALBUQUERQUE et al., 2014). The higher biomass production with biochar application shows it is possible to produce leguminous plants, similar to the common bean, to be used as green fertilizers, for example, in the recovery of degraded areas. Although, it was not within the scope of the present study, a higher number of nodules of nitrogen-fixing bacteria and greater number of fine roots were observed in the root system of plants that received biochar.

As with RDM and ASM, the application of increasing doses of biochar positively altered the other agronomic characteristics, as number of pods

(NP), number of grain (NG) and dry mass of grain (DMG) (Table 2). With the addition of 10% of BRHF, DMG increased from 3.39g plant<sup>-1</sup>, in the control treatment, to 18.73g plant<sup>-1</sup>. Conversely, the DMG maximum yield was 17.57g and 18.60g, obtained in the concentrations of 6.80% and 7.12% of BSF and BSSF, respectively.

The highest growth of common bean plants with increasing concentrations of biochar are related to higher nutrient absorption, since nutrient concentrations increased linearly with increasing biochar doses (Table 3). In general, it was observed that the positive effects of the biochar on the evaluated agronomic characteristics are related to the conditioning effect on the chemical, physical

Table 2 - Adjusted regression equations between dry mass of grains, number of pods and number of grains and doses of biochar.

Variables	Biochar	Equations	R <sup>2</sup>	Vmax	Nmax
DMG (g plant <sup>-1</sup> )	BRHF	$y=3.9305+1.4801^{**}x$	0.94	18.73	10
	BSF	$y=3.1153+4.2542^{**}x-0.313^{**}x^2$	0.97	17.57	6.80
	BSSF	$y=4.0061+3.5471^{**}x-0.2163^{**}x^2$	0.90	18.60	7.12
NP	BRHF	$y=9.81+1.164^{**}x$	0.97	21.45	10
	BSF	$y=9.6529+3.3744^{**}x-0.2139^{**}x^2$	0.95	22.96	7.89
	BSSF	$y=9.5386+3.6591^{**}x-0.2577^{**}x^2$	0.98	22.53	7.10
NG	BRHF	$y=18.45+6.26^{**}x$	0.95	81.05	10
	BSF	$y=16.275+19.102^{**}x-1.4233^{**}x^2$	0.96	79.82	6.68
	BSSF	$y=18.243+16.866^{**}x-1.1286^{**}x^2$	0.91	81.25	7.47

Vmax. = Maximum value of the response variable estimated by the regression equation; Nmax. = Biochar level corresponding to the maximum value of the response variable; BRHF = Biochar from rice husk filter; BSF = Biochar from sawdust filter; BSSF = Biochar from sorghum silage filter; DMG = Dry mass of grain; NP = Number of pods; NG = Number of grain. P<0.05; \*\*:P<0.01.

and biological soil properties, as previously described. Although, still little known, biochar can affect the plant physiology. Biochar had an effect on water relations, increasing relative water content and leaf osmotic potential, decreasing stomatal resistance and stimulating foliar (transpiration) gas exchange, and on photosynthesis by increasing the electron transport rate of photosystem II and the relation between effective photochemical quantum yield and non-photochemical quenching (HAIDER, et al., 2015).

VIGER et al. (2015), verified for plants of *Arabidopsis thaliana* and lettuce that a total of 1076 genes differently expressed when comparing control plants with plants grown in biochar at 50Mg ha<sup>-1</sup>, both with fertilizer. These authors verified effect of biochar application on growth, cell morpho-genesis, response to stimulus or stress, hormones, such as jasmonic acid, auxin and cytokinin, and secondary metabolism. However, few effects were reported for genes controlling photo-synthetic pathways. These results suggesting enhanced growth was underpinned

Table 3 - Adjusted regression equations between nutrients concentration in common bean leaves and doses of biochar.

Nutrient	-----Biochar-----					
	-----BRHF-----		-----BSSF-----		-----BSF-----	
N	$y = 2.535+0.108^{**}x$	R <sup>2</sup> = 0.93	$y = 2.24+ 0.112^{**}x$	R <sup>2</sup> = 0.98	$y = 1.90+ 0.08^{**}x$	R <sup>2</sup> = 0.91
P	$y = 0.22+0.052^{**}x$	R <sup>2</sup> = 0.99	$y = 0.183+0.050^{**}x$	R <sup>2</sup> = 0.96	$y = 0.16+0.048^{**}x$	R <sup>2</sup> = 0.95
K	$y = 2.45+0.14^{**}x$	R <sup>2</sup> = 0.95	$y = 2.32+0.116^{**}x$	R <sup>2</sup> = 0.94	$y = 2.24+0.112^{**}x$	R <sup>2</sup> = 0.98
Ca	$y = 2.48+0.144^{**}x$	R <sup>2</sup> = 0.93	$y = 2.39+0.136^{**}x$	R <sup>2</sup> = 0.92	$y = 2.32+0.124^{**}x$	R <sup>2</sup> = 0.94
Mg	$y = 0.267+0.038^{**}x$	R <sup>2</sup> = 0.98	$y = 0.241+0.040^{**}x$	R <sup>2</sup> = 0.99	$y = 0.2450.04^{**}x$	R <sup>2</sup> = 0.99
S	$y = 0.100+0.006^{**}x$	R <sup>2</sup> = 0.96	$y = 0.102+0.005^{**}x$	R <sup>2</sup> = 0.98	$y = 0.107+0.005x$	R <sup>2</sup> = 0.94
B	$y = 87.45+3.36^{**}x$	R <sup>2</sup> = 0.98	$y = 87.46+3.16^{**}x$	R <sup>2</sup> = 0.98	$y = 90.15+2.52^{**}x$	R <sup>2</sup> = 0.96
Zn	$y = 34.55+2.32^{**}x$	R <sup>2</sup> = 0.98	$y = 35.11+2.14^{**}x$	R <sup>2</sup> = 0.97	$y = 34.98+1.94^{**}x$	R <sup>2</sup> = 0.93
Cu	$y = 6.215+0.352^{**}x$	R <sup>2</sup> = 0.92	$y = 6.135+0.328^{**}x$	R <sup>2</sup> = 0.92	$y = 6.33+0.304^{**}x$	R <sup>2</sup> = 0.95
Fe	$y = 335.4+25.74^{**}x$	R <sup>2</sup> = 0.95	$y = 334.1+25.12^{**}x$	R <sup>2</sup> = 0.94	$y = 339.6+23.58^{**}x$	R <sup>2</sup> = 0.95
Mn	$y = 153.6+15.03^{**}x$	R <sup>2</sup> = 0.98	$y = 157.5+13.64^{**}x$	R <sup>2</sup> = 0.98	$y = 157.7+12.36^{**}x$	R <sup>2</sup> = 0.97

BRHF = Biochar from rice husk filter; BSF = Biochar from sawdust filter; BSSF = Biochar from sorghum silage filter. \*\*:P<0.01.

by increased cell expansion and enhanced activity in membrane transporter genes for sugar, nutrients and aquaporins for better water and nutrient uptake and movement of sugars for metabolism in the plant. However, these positive effects on growth were linked to large and consistent down-regulation of genes controlling plant defence mechanisms, including the jasmonic and salicylic acid biosynthetic pathways, which all have roles in plant defense against pathogens and pest attacks (VIGER et al., 2015).

It should be noted that in the present study the doses of biochar were high. In commercial crops, these doses are justified if it is to give an environmentally correct destination to a waste with polluting potential and, or when there is a large amount of organic waste that needs to be properly disposed of (GWENZI et al., 2015). However, in some studies small doses of biochar associated with mineral fertilizers have increased the efficiency of these inputs (MANIKANDAN & SUBRAMANIAN, 2013), which seems to be more feasible when the raw material for the production of biochar is limiting.

## CONCLUSION

The biochar promoted the greatest development of the plant with an increase in root dry mass, dry shoot mass, number of pods, number and dry mass of the grains. In general, the doses of 10% of BRHF, 7% of BSF and 7% of BSSF were the ones that gave the highest number of pods, number of grains, consequently, higher grain dry mass production.

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