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Sugarcane bagasse ash doses affect soil chemical attributes and pigeon pea initial performance

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ABSTRACT

Brazil stands out in the international scenario as the largest producer of sugarcane, processing billions of tons. Thus, this activity generates residues, such as ashes from bagasse burning and straw from sugarcane cleaning and from the production of sugar, alcohol and thermal energy. Therefore, the objective was to evaluate the initial performance and chlorophyll content of pigeon pea and the chemical attributes of the soil after application of ash doses. The experiment was conducted in 2021, in a greenhouse located in southwestern Goiás, Brazil. The design used was completely randomized, composed of five ash doses: 10, 20, 30, 40 and 50 Mg ha^{-1} and a control treatment, with four replicates, totaling 24 experimental units. The use of only ash as a fertilizer source causes linear increases in the initial growth of pigeon pea and in the contents of total chlorophyll and chlorophyll *b*, reaching the maximum increments with the estimated ash doses of 35.9 and 38.9 Mg ha^{-1}. Applications of high ash doses promoted improvements in soil fertility, with increase in pH, P, K and base saturation as well as reduction in aluminum content and aluminum saturation. Calcium and magnesium contents reached the maximum increments with the estimated ash doses of 39.5 and 66.7 Mg ha^{-1}, respectively.

Keywords: Organic residue, Chlorophyll, Soil fertility.

Doses de cinzas do bagaço da cana-de-açúcar afeta os atributos químicos do solo e o desempenho inicial de feijão guandu

RESUMO

O Brasil destaca-se no cenário internacional como o maior produtor de cana-de-açúcar, onde são processados bilhões de toneladas. Assim, são gerados resíduos dessa atividade, podendo-se destacar as cinzas provenientes da queima do bagaço e palhadas oriundas da limpeza da cana e da produção de açúcar, álcool e energia térmica. Portanto, objetivou-se avaliar o desempenho inicial e teor de clorofila do feijão guandu e os atributos químicos do solo após a utilização de doses de cinzas. O estudo foi conduzido no ano de 2021, em casa de vegetação localizada no Sudoeste Goiano. O delineamento empregado foi em delineamento inteiramente ao acaso, composto por cinco doses de cinzas: 10; 20; 30; 40 e 50 Mg ha^{-1} e um tratamento controle, com quatro repetições, totalizando 24 unidades experimentais. A utilização somente de cinzas como fonte de fertilizante aumenta linearmente o crescimento inicial do feijão guandu como também incrementos nos teores de clorofila total e clorofila B, atingindo os máximos incrementos com as doses estimadas de cinzas de 35.9 e 38.9 Mg ha^{-1}. Aplicações de altas doses de cinzas promoveram melhorias na fertilidade do solo, com aumento de pH, P, K, saturação por bases e redução dos teores de alumínio e saturação por alumínio. Os teores de cálcio, magnésio atingiram os máximos incrementos com as doses estimadas respectivamente de 39.5 e 66.7 Mg ha^{-1} de cinzas.

Palavras-chave: Resíduo orgânico, Clorofila, Fertilidade do solo.

1. Introduction

The state of Goiás stands out in the national scenario as an important center of production of agricultural products. The main producing activities are pastures, under intensive system or even extensively underutilized for meat and milk production and for the production of grains, mainly soybean and corn (Pinto et al., 2012). In addition, it is worth pointing out that in the last two decades there have also been activities of production of ethanol, sugar and energy, from sugarcane.

In the 2022/2023 harvest, a production of 72.5 million tons is estimated, in Goiás, considered the second largest producer of sugarcane (Seapa, 2022). This large amount can increase state production by 0.7%, with Goiás participating in 12% of the estimated national production and 54.6% in the Midwest region. Thus, due to this considerable production of sugarcane, large amounts of residues are generated, such as ashes from the burning of sugarcane bagasse to produce thermal energy. These ashes must have an appropriate destination to avoid contamination of the environment. Among these destinations, ashes can be used as an alternative source for mineral fertilization and the two forms of fertilization can be associated (Li et al., 2021; Tian et al., 2021).

Biochars can have varied composition, as well as the raw material for their manufacture, and can come from very different materials such as rice straw, corn stem, sugarcane bagasse, forest residues, sewage sludge and others (Zhang et al., 2021). To evaluate or estimate soil quality, indicator attributes such as chemical, physical and biological attributes are often used. Residues from the agroindustry, besides being used as a source of fertilizer, can improve soil quality (Pinto et al., 2012; Ribeiro et al., 2019; Zhang et al., 2021).

The use of biochar can increase soil fertility by providing some cations such as Ca, Mg, K, Mn, Zn and Cu and also through the presence of other nutrients such as P and N. Another factor that can be influenced by biochar application is the reduction of soil acidity, increase in carbon contents and reduction of heavy metals (Li et al., 2021; Tian et al., 2021; Zhang et al., 2021).

The use of biochar has been reported in some crops: in papaya associated with microorganisms (Matos et al., 2018), in rapeseed associated with mineral fertilizers (Tian et al., 2021) and in Brazilian peppertree (Sales et al., 2018). This residue supplies nutrients to plants and can increase their performance, increase the contents of total chlorophyll, chlorophyll *a* and chlorophyll *b*, as well as improving the chemical attributes of the soil (Matos et al., 2018; Sales et al., 2018; Li et al., 2021). Although some sources of ash are reported in the literature, there are still few studies on the effects of using ash from sugarcane bagasse burning on pigeon pea crop and soil chemical attributes, requiring information mainly when it is used as the only source of fertilizer and at high doses. Therefore, the present study aimed to evaluate the initial performance and chlorophyll content of pigeon pea and the chemical attributes of the soil after application of ash doses.

2. Material and Methods

The study was conducted in 2021, in a greenhouse located in experimental area, in the municipality of Mineiros, GO, Brazil. The soil used was classified as Neossolo Quartzarênico (Quartzipsamment) (SANTOS et al., 2018) and contains 100 g kg^{-1} of clay, 50 g kg^{-1} of silt and 850 g kg^{-1} of sand in the 0-0.2 m layer. For chemical characterization of each treatment, a sample was collected in the 0-0.2 m layer (Table 1), and the chemical analyses were performed according to Teixeira et al. (2017).

The design used was completely randomized, composed of five doses of ash: 10; 20, 30, 40 and 50 Mg ha^{-1}, plus a control treatment, with four replicates, totaling 24 experimental units. The ashes used are derived from the burning of sugarcane bagasse for thermal energy production. The chemical composition of the ashes used is presented in Table 2, and the analyses were performed according to Teixeira et al. (2017).

Table 1. Basic chemical characterization of the soil in the experimental area, in the 0-0.2 m layer.

pH	OM	P	K	Ca	Mg	Al	H+Al	SB	CEC	V
$CaCl_2$	g dm^{-3}	---mg dm^{-3}-----		-------------------------------cmol$_c$ dm^{-3}--------------------------------						%
4.0	18.7	1.02	22	0.76	0.25	0.56	2.47	1.07	3.54	30.2

pH – hydrogen potential; OM – organic matter; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; Al – aluminum; H+Al – potential acidity; SB – sum of bases; CEC – Cation exchange capacity; V% – base saturation

Table 2. Chemical composition of the ashes used as a fertilizer source in pigeon pea crop.

N	P_2O_5	K_2O	Ca	Mg	C-organic	Dry matter	pH	C:N
-- g kg^{-1} --								
10.5	2.6	3.6	4.8	1.4	56.4	983.5	7.1	5.4:1

N – nitrogen; P_2O_5 – phosphorus; K_2O – potassium; Ca – calcium; Mg – magnesium; C-organic – organic carbon; pH – hydrogen potential; C:N – carbon to nitrogen ratio.

Each experimental unit consisted of a pot with 7 dm^3 capacity, which received 5 dm^3 of soil sieved through a 0.002 m mesh and dried in the shade. The ash doses of these treatments were mixed to the soil and incubated for 150 days, with an average temperature of 25 °C, maintaining soil moisture at 70% of field capacity. The pots were placed in a greenhouse on May 3, 2021, where the ashes were mixed to the soil and incubated for 97 days until August 8, 2021, and 5 seeds of pigeon pea were sown.

After 7 days, the plants were thinned and only two were kept in each pot. Throughout the evaluation period, soil moisture was maintained at 70% of field capacity. Pigeon pea was cultivated for 47 days, until the V4 stage, when it was evaluated on September 23, 2021, to determine dry matter, chlorophyll *a*, chlorophyll *b* and total chlorophyll. To determine the dry matter of each plant, the material was collected, taken to an oven at 65 ºC and kept for 48 hours. The photosynthetic pigments chlorophyll *a*, chlorophyll *b* and total chlorophyll were obtained using the portable chlorophyll meter ClorofiLOG® (CFL1030; Falker, Porto Alegre, RS, Brazil).

With the portable device, by pressing the leaves on its sensor, two measurements of chlorophyll *a* and chlorophyll *b* were performed. Immediately after pigeon pea harvest, the soil of each pot was air dried and sieved through a 0.002 m mesh (ADFE) for subsequent determination of the contents of Organic Carbon, P, K, Ca, Mg, Al, in addition to pH, CEC, V%, aluminum saturation (m%) and H+Al (Teixeira et al., 2017). For comparison of ash doses, the data were subjected to analysis of variance and, when significant, to polynomial regression analysis. A biplot chart was then used to check the overall variability of the experiment and the trends of the multivariate analysis. The analyses were carried out using the Rbio program with the R program interface (Bhering, 2017).

3. Results and Discussion

The dry matter of pigeon pea plants responded linearly to the increasing doses of ash, so the highest doses (40 and 50 Mg ha^{-1}) promoted increments of almost four times when compared to the control treatment (Figure 1). This increase in pigeon pea dry matter production may have been favored by the linear increases in soil pH, availability of nutrients, such as phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), and base saturation (V%), as well as the reduction of aluminum (Al) availability, as shown in Table 3.

In a study conducted in China with rapeseed under increasing doses of rice husk biochar, the best performance was obtained with 10 Mg ha^{-1} of biochar associated with 180 and 144 kg N ha^{-1} (Tian et al., 2021). The addition of biochar may increase the yield of some crops, as it promotes the activity of microorganisms present in the root zone. On the other hand, crop yield is not always increased and may even be reduced, which may be related to factors such as the amount of biochar added and also soil texture (Zhang et al., 2021). In a study carried out with rapeseed crop under increasing proportions of rice husk biochar in Eutric Regosol, plant biomass decreased at the highest proportions of this fertilizer (2 and 4% of total soil weight).

In this study, the base saturation was considered lower than indicated for the pigeon pea crop, that is 50%, and the P content was low even at the highest dose (Sousa and Lobato, 2004), which may have limited the yield of pigeon pea, causing the crop to still respond after the highest dose of ash (50 Mg ha^{-1}). The contents of total chlorophyll and chlorophyll *b* were influenced by the applications of increasing ash doses (Figure 2).

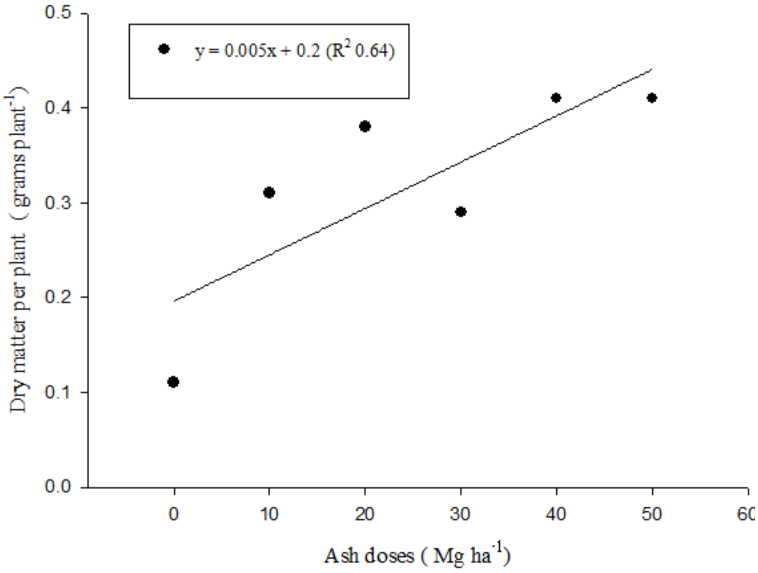

Figure 1. Dry matter of pigeon pea subjected to increasing doses of ash.

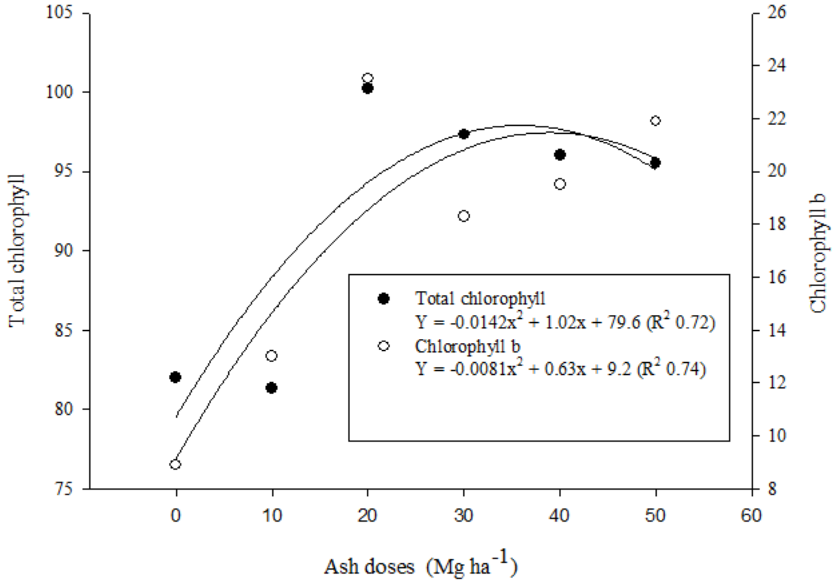

Figure 2. Concentrations of total chlorophyll and chlorophyll *b* (Spad index) in pigeon pea subjected to increasing doses of ash.

The highest total chlorophyll content was 97.9 with the estimated ash dose of 35.9 Mg ha^{-1}, a 19% increase compared to the control treatment. The highest chlorophyll *b* content was 21.4, obtained with the estimated ash dose of 38.9 Mg ha^{-1}, representing a 140% increase compared to the control treatment. For Golden papaya under different managements using biochar from the burning of poultry farm residue, the association between biochar and mycorrhizae led to the highest peaks of chlorophyll *a* and *b* (Matos et al., 2018).

A study on the development of Brazilian peppertree under different residues as substrate source showed changes in chlorophyll *b* contents when dairy residues and urban compost were used in the substrate (Sales et al., 2018). However, these same authors found no changes in chlorophyll *a* and total chlorophyll contents. In this study, the higher total contents of total chlorophyll and chlorophyll *b* with the increase in ash doses may be related to nutrients from the residue that are readily available, which can be assimilated and incorporated into carbon molecules reduced by photosynthesis (Matos et al., 2018). Another factor that may have contributed to the increase in the total chlorophyll and chlorophyll *b* contents may be related to the supply of N and Mg through the addition of ash, especially at the highest doses (Table 2). Increments in chlorophyll *b* contents are important, due to the capture of greater amount of incident light to the action site of the photosystems, leading to a greater formation of ATP and NADPH, which will be used by the plant in the photosynthetic process, increasing the yield (Whatley and Whatley, 1982)

The soil pH values increased as higher doses of ash were added to the soil (Table 3), with the opposite effect for aluminum saturation (m%), as well as reduction in the contents of this element. The estimated ash dose of 80 Mg ha^{-1} led to the lowest Al content, 0.003 cmol$_c$ dm^{-3}. The increase in pH as a function of increasing ash doses may be related to the pH of the residue, which is 7.1. The high pH values of the biochar may be related to the pyrolysis process, in which acid groups of residues are decomposed and volatilized during burning (Zhang et al., 2021). Increase in pH values and reduction in m%, with the use of residues from agroindustry, such as turkey litter, are reported by other authors (Ribeiro et al., 2019). This fact may be related to the hydrolysis of this element, which occurs with the increase in pH values, causing its precipitation as its charges are cancelled out (Ribeiro et al., 2019). Aluminum saturation changed from 34% in the control treatment to 10% at the highest dose used for this residue from the agroindustry. The reduction of Al is important, because it is an element with negative effects on the development of many plant species, such as cell damage and reductions in cell division and root development (Fagan et al., 2016).

The P and K contents increased as the ash dose increased. The increments in P contents from the highest ash dose to the control treatment was more than 7 times. The K contents were increased by more than 4 times from the highest dose to the control treatment. In rapeseed cultivation in Eutric Regosol in China, P and K contents were increased with the increase in the biochar proportion relative to the amount of soil, corroborating the results found in the present study (Li et al., 2021). This increment of more than 4 times in K content in the soil with the use of ash, at the highest dose, allowed the contents of this element to change from low to high (Sousa and Lobato, 2004).

The highest Ca content was obtained with the estimated ash dose of 39.5 Mg ha^{-1}, 0.9 cmol$_c$ dm^{-3}. The behavior of Mg was similar to that of Ca, and the highest content was 0.36 $cmol_c\ dm^{-3}$, obtained with the estimated ash dose of 66.7 Mg ha^{-1}. The increase in Ca, Mg and K contents promoted the highest increments in the sum of bases, and maximum increment was obtained with the estimated ash dose of 85 Mg ha^{-1}, which led to a content of 1.75 $cmol_c\ dm^{-3}$. These increments in the bases are important because they were able to increase base saturation (V%), so that the increase in ash doses promoted increments of more than 10% with the use of the highest ash dose, when compared to the control treatment.

According to Zhang et al. (2021), the use of biochar can increase the contents of cations in the soil, such as Ca, Mg and K, and consequently increase V%. Despite increasing V%, the amount of bases is still lower than recommended for the pigeon pea crop, which is 50% (Sousa and Lobato, 2004). Therefore, for soils with low natural fertility, even the highest doses were not sufficient to raise fertility and replace liming and phosphate fertilization. Thus, it is suggested that the use of ash is a way of complementing mineral fertilization.

Total organic carbon and CEC were not influenced by the addition of ash (Table 3). In a study conducted with rice husk biochar, the increase in its proportion relative to the soil mass increased the organic carbon (C) contents, differing from the results found in the present study (Li et al., 2021). In the present study, as the soil was highly sandy, with 100 g kg^{-1} of clay, the physical and chemical protection of carbon for the formation organomineral complexes is more limited. Therefore, C accumulation in sandy soils is a more complex process, especially in tropical regions with high temperature, associated with constant humidity, which was monitored in our study.

Canonical variables were analyzed to verify the contribution of each variable (Figure 3). This technique is similar to principal component analysis, but it should be used when a study has an experimental design with repetitions (Baio et al., 2018). The accumulation of variances in the first two variables corresponded to 94%, which is higher than the recommended, of at least 80% (Mingoti, 2005). Thus, the canonical variables in this study can be used for an accurate interpretation.

The eigenvectors in Figure 3 show that m and Al were the closest variables to the control treatment and had a negative correlation with pH. The variables DM, CHLB and CHLTotal were close to each other, but were not close to any of the treatments. Ca, SB, Mg, pH, P and V were close to one another and to the highest dose of ash, showing a negative correlation with the control treatment and with m and Al. Therefore, the higher the levels of Ca, SB, Mg, pH, P and V, the lower the levels of Al and m.

Table 3. Chemical attributes of *Neossolo Quartzarênico* (Quartzipsamment) under increasing doses of ash.

Doses	pH	P	K	Ca	Mg	Al
Mg ha^{-1}	H_2O	---------mg dm^{-3} ---------		------------------$cmol_c\ dm^{-3}$------------------		
0	4	1	21.5	0.75	0.22	0.62
10	4.1	2.1	38	0.83	0.26	0.44
20	4.3	3	51.7	0.87	0.29	0.37
30	4.3	5.4	71	0.95	0.31	0.24
40	4.3	6.9	77.5	0.96	0.33	0.25
50	4.6	7.4	86.3	1.00	0.34	0.17
Regression fit	QR*$^{(1)}$	QR*$^{(2)}$	QR*$^{(3)}$	QR*$^{(4)}$	QR*$^{(5)}$	QR*$^{(6)}$
	H+Al	SB	CEC	Carbon	V%	M%
	---------$cmol_c\ dm^{-3}$--------			g dm^{-3}		
0	2.44	1.03	3.48	10.6	29.8	34.1
10	2.73	1.19	3.92	10.5	30.4	27.8
20	2.66	1.29	3.95	10.3	32.6	22.4
30	2.87	1.46	4.33	10.4	34.3	15.5
40	2.52	1.49	4.0	10.6	37.1	14.3
50	2.73	1.56	4.29	10.5	37.2	10.0
Regression fit	NS	QR*$^{(7)}$	NS	NS	QR*$^{(8)}$	QR*$^{(9)}$

*Quadratic regression significant at 5%; $^{(1)}$ $y = 0.012x + 3.99$ (R^2= 0.95); $^{(2)}$ $y = 0.14x + 0.85$ (R^2= 0.97); $^{(3)}$ $y= 1.32x + 24.7$ (R^2=0.97); $^{(4)}$ $y= -0.0001x^2 + 0.0079x + 0.75$ (R^2=0.97); $^{(5)}$ $y= -0.00003x^2 + 0.004x + 0.22$ (R^2=0.99); $^{(6)}$ $y= 0.0001 x^2 - 0.016x + 0.61$ (R^2=0.97); $^{(7)}$ $y= -0.0001 x^2 + 0.017x + 1.03$ (R^2=0.98); $^{(8)}$ $y= 0.16 x + 29.42$ (R^2=0.95); $^{(9)}$ $y = -0.48x + 32.46$ (R^2= 0.97).

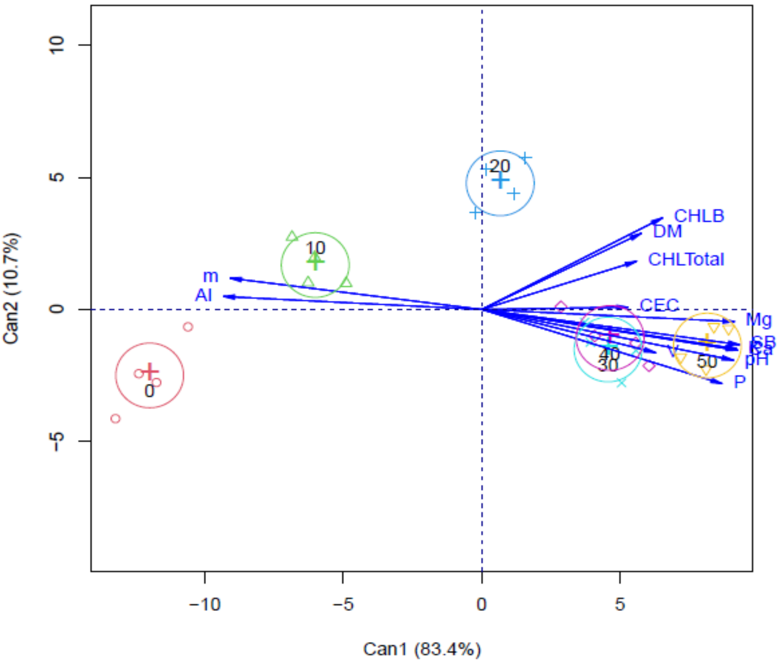

Figure 3. Analysis of canonical variables between aluminum (Al), aluminum saturation (m), base saturation (V), shoot dry matter (DM), total chlorophyll concentration (CHLTotal), chlorophyll b concentration (CHLB), cation exchange capacity (CEC), sum of bases (SB), pH, magnesium (Mg) and phosphorus (P). 0: control treatment; 10: 10 Mg ha^{-1} ash; 20 Mg ha^{-1} ash; 30 Mg ha^{-1} ash; 40 Mg ha^{-1} ash and 50 Mg ha^{-1} ash.

4. Conclusions

The dry matter yield of pigeon pea is linearly increased up to the ash dose of 50 Mg ha^{-1}. However, the total chlorophyll and chlorophyll *b* contents responded quadratically, with the highest increments at the estimated ash doses of 35.9 and 38.9 Mg ha^{-1}, respectively. Sequential applications of ash from sugarcane bagasse burning promoted improvements in soil fertility, with increments in pH, P, K, Ca, Mg, SB and base saturation as well as reductions in aluminum content and saturation.

Finally, even after using high doses of ash, its application in soils of low fertility should be combined with other sources of fertilizers and/or acidity correctives, because the P and base saturation levels are still below the recommended for pigeon pea growth

Authors' Contribution

Diego Oliveira Ribeiro, Zaqueu Henrique de Souza, Rogério Machado Pereira and Giovana Oliveira Rubio: Conceptualization, Formal analysis and Writing – original draft. Bruno Dalmolin and Jonathan Goularte Silva: Conceptualization, Methodology. All authors contributed toward interpreting the results, revising, and improving the paper.

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