Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Impacts of plant arrangement and nitrogen fertilization in the agronomic performance of grain sorghum

Impactos do arranjo de plantas e da fertilização nitrogenada no desempenho agronômico do sorgo granífero

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Submission: October 31th, 2025 | Acceptance: January 21th, 2026

ABSTRACT

New plant arrangements have proven to be beneficial for soybean cultivation. However, little is known about the performance of sorghum in these arrangements when grown in succession, particularly associated with nitrogen topdressing. Thus, the objective of this study was to evaluate the agronomic performance of grain sorghum grown in double rows and its response to nitrogen topdressing. Two experiments were conducted in the field in the Southwest of the State of Goiás, Brazil. In both, a 2x2 factorial randomized block design was adopted with six replications, corresponding to two row spacings (traditional - 0.50 m and double rows - 0.25x0.75 m) and the use or not of 90 kg ha^{-1} N as urea in topdressing. The grain sorghum hybrid used was Buster, and plant height, stem diameter, panicle length, shoot dry mass, thousand grain weight, and yield were evaluated. Double-row spacing did not change plant height or thousand-grain weight compared with traditional spacing. However, traditional spacing provided a higher grain yield than the double row spacing at both locations, with increases of 21% in Rio Verde (905 kg ha^{-1}) and 40% in Montividiu (1.879 kg ha^{-1}). The response of grain sorghum to nitrogen topdressing was variable in relation to the environment, with a 16% increase in grain yield in Rio Verde, without any influence from the plant arrangement.

KEYWORDS: Nitrogen topdressing. Row spacing. *Sorghum bicolor.* Urea. Yield.

RESUMO

Novos arranjos de plantas têm se mostrado benéficos para o cultivo da soja. No entanto, pouco se sabe sobre o desempenho do sorgo nesses arranjos quando cultivado em sucessão, particularmente quando associado à adubação nitrogenada em cobertura. Assim, o objetivo deste estudo foi avaliar o desempenho agronômico do sorgo granífero cultivado em fileiras duplas e sua resposta à adubação nitrogenada em cobertura. Dois experimentos foram conduzidos a campo na região sudoeste do Estado de Goiás, Brasil. Em ambos, adotou-se o delineamento experimental em blocos casualizados em esquema fatorial 2x2 com seis repetições, correspondendo a dois espaçamentos entrelinhas (tradicional - 0,50 m e fileiras duplas - 0,25x0,75 m) com ou sem aplicação de 90 kg ha^{-1} de N na forma de ureia em cobertura. O híbrido de sorgo granífero utilizado foi o Buster, sendo avaliadas a altura da planta, o diâmetro do colmo, o comprimento da panícula, a massa seca da parte aérea, a massa de mil grãos e a produtividade. O arranjo de fileiras duplas não alterou a altura da planta nem a massa de mil grãos em comparação ao tradicional. Contudo, o espaçamento tradicional proporcionou rendimento de grãos superior ao de fileiras duplas em ambas as localidades, com aumentos de 21% em Rio Verde (905 kg ha^{-1}) e de 40% em Montividiu (1.879 kg ha^{-1}). A resposta do sorgo granífero à adubação nitrogenada de cobertura foi variável em relação ao ambiente, com aumento de 16% no rendimento de grãos em Rio Verde, sem qualquer influência do arranjo de plantas.

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PALAVRAS-CHAVE: Adubação nitrogenada de cobertura. Espaçamento entrelinhas. *Sorghum bicolor.* Ureia. Rendimento de grãos.

INTRODUCTION

In Brazil, sorghum is cultivated in the off-season, normally from February after the soybean harvest for grain production, to meet the needs of agro-industries in the region. This period is characterized by a decrease in the light period, average temperature, and amount of rainfall, often causing post-flowering water stress (BATISTA et al. 2017).

The species in question have special characteristics that allow better tolerance to water deficit compared to other cereals, highlighting their accurate stomatal adjustment, presence of waxy cover on leaves and stems, ability to make changes in leaf angulation, and ability to promote leaf curling (ASSEFA & STAGGENBORG 2011). With an abundant and deep root system compared to other cereals (UBERT & SOLIGO 2015), sorghum produces a large amount of straw with a high C/N ratio, which confers a slower decomposition, an important characteristic for maintaining no-till systems (ALBUQUERQUE et al. 2013).

Despite the great production potential of this grain in Brazil, the country was the third largest producer of sorghum in the 2024/2025 harvest, behind only the USA and Nigeria (USDA 2026). In addition to the enormous possibility of increasing the areas cultivated with crops in the no-till system, Brazil has low yield. According to CONAB (2026), the national average in 2025 agricultural year was 3,670 kg ha^{-1}, far below its potential, which according to RESENDE et al. (2009), can reach 12,000 kg ha^{-1}. Factors explaining the low yield of sorghum include the absence of topdressing fertilization with an insufficient supply of nutrients to achieve higher yield, in addition to the need for adjustments in the arrangement of plants.

Nitrogen topdressing is not a common practice in grain sorghum, especially when it is grown in the off-season (GOES et al. 2011). However, nitrogen is one of the nutrients most required by crops, which accumulate linearly in plants until maturity, and its use by mineral fertilizers depends on the predecessor crop (FONTES et al. 2017). According to SANTI et al. (2006), N deficiency in sorghum plants can cause chlorosis in older leaves, acquiring a yellowish color, in addition to causing a reduction in size, smaller stem thickness, predisposition to lodging, and reduction in leaf area. The authors also argued that if the deficiency persists, chlorosis is observed in younger leaves. Important highlight hybrids respond differently to nitrogen fertilization (OSTMEYER et al. 2022), and this nutrient contributes to the accumulation of dry mass (GOES et al. 2011, CARVALHO et al. 2022).

The spatial arrangement of plants in the cultivation area is another factor that directly affects grain yield, as adequate arrangements can result in greater use of water, light, and nutrients (CARMO et al. 2020). BRUNS (2011) evaluated the behavior of soybean crop in a double row system and reported that in this plant arrangement, there can be high penetration of light and agrochemicals in the canopy, improving the photosynthetic rate, health, and longevity of leaves close to the ground, which can ultimately maximize grain yield. RONCUCCI et al. (2014) observed increases of up to

20% in sorghum biomass productivity for energy purposes with the use of double row spacing (0.20x0.80 m) compared to conventional spacing (0.50 m between rows). In corn, BETTIO et al. (2017) found that sowing in double rows (0.20/0.70 m) resulted in a higher grain yield than traditional cultivation with single spacing (0.45 m).

Due to the scarcity of results for the doublerow cultivation of sorghum in the off-season, there is a need to investigate the feasibility of this system combined with N topdressing in the off-season. It is expected that the double-row planting system combined with the use of nitrogen topdressing can improve the formation of the productivity components of the sorghum crop, providing a higher grain yield. Given this context, the objective of this study was to evaluate the agronomic performance of a grain sorghum hybrid cultivated in a double row system and its response to the use of nitrogen topdressing.

MATERIAL AND METHODS

Two experiments were carried out in the field in two important sorghum-producing regions in the state of Goiás, one in the municipality of Rio Verde (17°52'55" S and 50°55'43" W, 741 m altitude) and another in Montividiu (17°22'58" S and 51°22'40" W, 910 m altitude), both in the off-season of 2018.

The climate of these two municipalities is classified as Aw according to the Köppen classification, with a dry period in the winter and rainfall concentrated in the summer, with annual average temperatures of 23.3 and 23.0 °C and rainfall of 1,663 and 1,512 mm, respectively, for Rio Verde and Montividiu (CLIMATE-DATA 2021). Data on rainfall, average temperature, and relative air humidity between sowing and harvesting, by location, are presented in Figure 1.

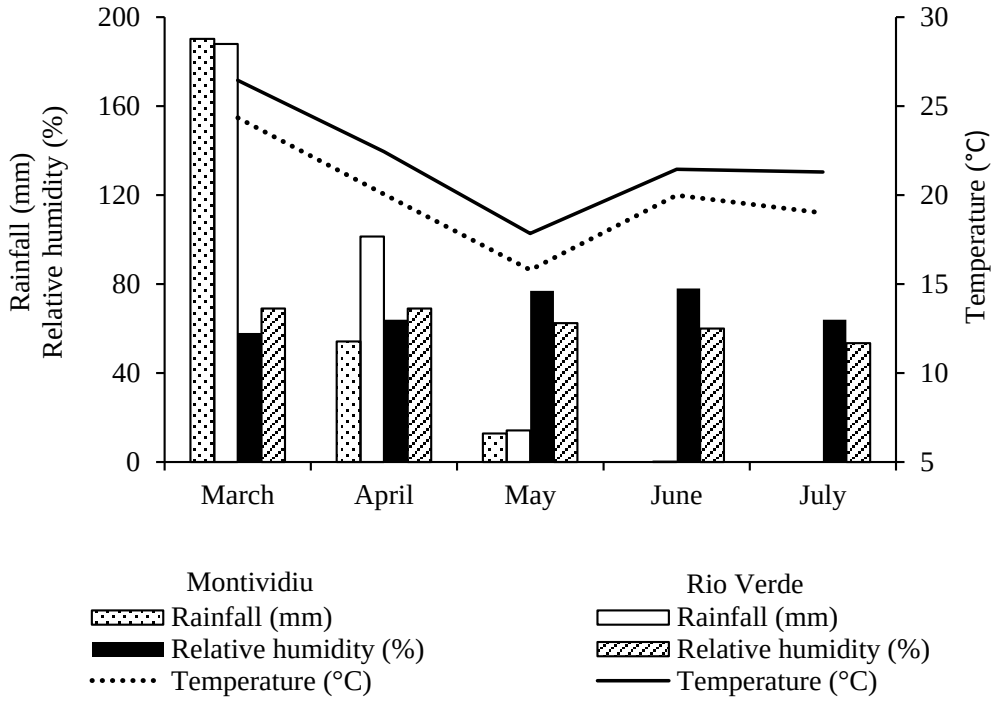


Figure 1. Data on rainfall data (mm), relative air humidity (%) and average temperature (°C) during the experimental period in Montividiu and Rio Verde, Goiás State, 2018.

The soil of the experimental area in Rio Verde was classified as *Latossolo Vermelho* (SANTOS et al. 2018) with the following properties (0.0 to 0.2 m layer) (very low-VL; low-L; medium-M; adequate-A; high-H, and very high-VH) (SOUZA & LOBATO 2004) at the time of implementation of the experiment: pH in $CaCl_2$: 5.3 (A); Ca: 4.1 (A); Mg: 1.2 (A); K: 0.3 (H); Al: 0.0 (L); H + Al: 2,8; and cation exchange capacity: 8.4 (A) in $cmol_c\ dm^{-3}$; base saturation: 67% (H); P: 3.7 mg dm^{-3} (L); Cu: 2.5 (H), Zn: 1.9 (H), Fe: 55.1 and Mn: 147.1 (H) in mg dm^{-3}; organic matter: 24.0 g dm^{-3} (A); clay: 349, silt: 122 and sand: 529 g kg^{-1}, respectively.

The soil of the Montividiu experimental area was classified as *Latossolo Vermelho-Amarelo* (SANTOS et al. 2018), with the following physical and chemical characterization in the 0.0-0.2 m layer: pH in $CaCl_2$: 5.9 (VH); Ca: 3.0 (A); Mg: 0.7 (A); K: 0.2 (A); Al: 0.0 (L); H + Al: 3.6; cation exchange capacity: 7.6 (A) in $cmol_c\ dm^{-3}$; base saturation: 87% (VH); P: 26.8 mg dm^{-3} (A); Cu: 3.6 (H); Zn: 12.1 (A); Fe: 56.8, and Mn: 159.9 (H) in mg dm^{-3}, respectively; organic matter: 18.7 g dm^{-3} (M); clay: 226, silt: 78 and sand: 696 g kg^{-1}, respectively.

The experiments were set up in a 2x2 factorial randomized block design with six replications, corresponding to the following factors: two row spacings (traditional - 0.50 m and double rows - 0.25x0.75 m); and use or not of nitrogen topdressing with 90 kg ha^{-1} N as urea to achieve a grain yield of 5,500 kg ha^{-1} (SOUZA & LOBATO 2004), when sorghum plants had four fully developed leaves. The experimental plots were 6.0 m in length and contained four rows spaced 0.50 m apart (conventional spacing) or four rows spaced alternately at 0.25 and 0.75 m (double row spacing), totaling 12.0 m^2. To compose the useful area, the two external rows and 0.50 m from each end of the plots were disregarded, forming an area for evaluation of 5.0 m^2.

In both experimental settings, sorghum was mechanically sown on March 14 and 15 in Rio Verde and Montividiu, respectively, within no-till areas following soybean cultivation. The Buster hybrid, characterized by medium size, a super-early growth cycle, semi-open panicles, and red grains devoid of tannin, was sown at a depth of 3 cm. Seed density was calibrated to achieve a final population of 200,000 plants per hectare across all treatments.

Basal fertilization and seed treatment were not performed in the two experimental areas. During the experiments, manual weeding was carried out, maintaining the sorghum crop without interference from weeds. Insecticides and fungicides were not applied in the experiments, according to the monitoring carried out for the detection of pests and diseases.

Evaluations of agronomic characteristics were similar in the two experiments, which were carried out 115 days after emergence (DAE). Plant height, panicle length, stem diameter, and shoot dry biomass were obtained from the average of five plants randomly sampled in the useful area of the plots. A graduated measuring tape was used to measure plant height, taking the distance from the base of the plant to the end of the panicle as a reference, and to measure the length of the panicles. Stem diameter was measured using a digital caliper, measuring the portion of the stem located below the most basal leaf. The dry biomass of sorghum plants was determined after weighing the plant shoot after drying in a forced air oven at 65 °C for 72 h.

At the time of harvest, at 120 DAE, the number of panicles per hectare was determined after counting those present in the useful area of the plot; grain yield (kg ha^{-1}) was determined by collecting and threshing the grains, with subsequent weighing and moisture correction to 13%; and the thousand grain weight was determined by weighing thousand grains with moisture corrected to 13%.

Statistical analysis was performed separately for each experiment using SISVAR statistical software (FERREIRA 2011). Data were tested by analysis of variance using the F-test (*p≤0.05*) after meeting the requirements for conducting an analysis of variance. When significance was found for the sources of variation, Tukey's test was performed (*p≤0.05*), and further analysis was performed when necessary.

RESULTS AND DISCUSSION

The results showed no interaction was observed between row spacing and nitrogen fertilization in relation to the final height of the grain sorghum plants at the two evaluated locations (Table 1). Additionally, the use of double row spacing (0.25x0.75 m) did not affect the height of sorghum plants compared to conventional spacing (0.50 m) in the experiments conducted in Rio Verde and Montividiu. This result corroborates that of CARMO et al. (2020), who found no differences in the final height of plants of the grain hybrid Dow 1G245 grown in double rows (0.25x0.75 m) or in conventional spacing (0.50 m). These results suggest that the variable in question is more related to the genetic factors of grain sorghum hybrids than to the double-row arrangement of plants.

Table 1. Height and stem diameter of grain sorghum plants cultivated in two row spacings with or without nitrogen topdressing.

Topdressing	Spacing (m)					
	0.50	0.25x0.75	Means	0.50	0.25x0.75	Means
	Plant height (cm)			Stem diameter (mm)		
			Rio Verde (Brazil)			
90 N	133.83	136.83	135.33	11.60 Ba	13.30 Aa	12.45
0 N	134.33	136.67	135.50	11.83 Aa	11.30 Ab	11.57
Means	134.08	136.75		11.72	12.30	
CV (%)		4.40			9.16	
			Montividiu (Brazil)			
90 N	134.63	133.60	134.12 a	12.53	11.50	12.02
0 N	130.40	129.47	129.93 b	13.30	17.10	15.20
Means	132.52	131.53		12.92	14.30	
CV (%)		2.58			31.42	

Means followed by different lowercases, in the same column, and uppercases, in the same row, are significantly different by Tukey's test (*p≤0.05*). CV (%): coefficient of variation.

Unlike row spacing, N topdressing in sorghum cultivated in Montividiu increased plant height regardless of the spacing used (Table 1). This can be attributed to the lower organic matter content in the soil compared to that in Rio Verde. Thus, topdressing with nitrogen in Montividiu contributed to greater plant growth, even with the supply of nitrogen, through the mineralization of organic matter, to the crops cultivated in succession (KEBENEY et al. 2017). However, the increase was slightly more than 4 cm. In both experiments, the plants of the Buster hybrid presented an average height greater than 130 cm (135 and 132 cm in Rio Verde and Montividiu,

respectively). It is also noteworthy that due to the more compact architecture and earlier size of this hybrid, it is necessary to use a larger plant population (200,000 plants ha^{-1}) in relation to those commonly used in the market. However, this larger population combined with the increase in size provided by nitrogen topdressing was insufficient to cause lodging in the field.

For stem diameter, an interaction between row spacing and nitrogen fertilization was observed in Rio Verde (Table 1). In this case, N topdressing contributed to the increase in values when the Buster hybrid was seeded in double-row spacing (average increase of 2 cm). In addition, with N topdressing, sorghum plants had a larger stem diameter when grown in double-row spacing than when grown in conventional spacing. In Montividiu, no effect of row spacing or N application on stem diameter was detected, with an average value of 13.61 mm. CARVALHO et al. (2022) noted the effects of spacing and N fertilizer on stem diameter in sorghum, with larger stem diameters of the grain hybrid AG1085 when cultivated at a spacing of 0.50 m and fertilized with 150 kg ha^{-1} N, with 50% of the fertilizer applied at sowing and the rest as topdressing when the plants had six developed leaves.

In Rio Verde, the panicle length of grain sorghum was influenced by the interaction between row spacing and N topdressing (Table 2). Thus, the application of N resulted in greater growth of this reproductive structure in double row spacing (increase of 1.93 cm). In the other experimental location, greater panicle length was found in plots with conventional spacing (0.50 m) than in double rows (0.25x0.75 m), regardless of the use of N.

Table 2. Panicle length and shoot dry mass of grain sorghum plants cultivated in two row spacings with or without nitrogen topdressing.

Topdressing	Spacing (m)					
	0.50	0.25x0.75	Means	0.50	0.25x0.75	Means
	Panicle length (cm)			Shoot dry mass (kg ha^{-1})		
			Rio Verde (Brazil)			
90 N	25.30 Aa	26.53 Aa	25.92	14,95 Aa	16,11 Aa	15,527
0 N	25.60 Aa	24.60 Ab	25.10	14,85 Aa	11,07 Bb	12,962
Means	25.45	25.57		14,89	13,59	
CV (%)		4.71			9.84	
			Montividiu (Brazil)			
90 N	25.60	24.00	24.80	24,793	19,004	21,898
0 N	25.83	25.13	25.48	22,383	19,554	20,968
Means	25.72 A	24.57 B		23,588 A	19,279 B	
CV (%)		3.92			9.76	

Means followed by different lowercases, in the same column, and uppercases, in the same row, are significantly different by Tukey's test (*p≤0.05*). CV (%): coefficient of variation.

The shoot dry mass of grain sorghum plants evaluated in Rio Verde was influenced by the interaction between row spacing and N topdressing (Table 2). Positive responses to N application occurred only in plots where sorghum was sown in double rows, as observed for panicle length. In this location, conventional spacing resulted in higher shoot dry mass production than double rows, but only in plots that did not receive N topdressing. In Montividiu, the highest value was also observed in the conventional spacing, but this effect was not related to the use of N. Due to super early growth cycle of Buster hybrid and be cultivated after soybean, which the sorghum

maybe N uptake (KEBENEY et al. 2017) the results obtained in Montividiu do not corroborate other studies that found a significant increase in sorghum biomass with increasing nitrogen fertilization of 90 kg ha^{-1} (ALMODARES et al. 2009) for sweet sorghum and 85 kg ha^{-1} (SIGUA et al. 2018) in two grain sorghum hybrids.

The thousand grain weight was not affected by either row spacing or N topdressing in the experiments carried out in Rio Verde and Montividiu (Table 3). Thus, the mean values were 25.19 g and 25.07 g for Rio Verde and Montividiu, respectively. The use of double row spacing caused reductions in grain yield of grain sorghum compared to conventional spacing, regardless of the use of N topdressing, in the two evaluated locations in southwestern Goiás (Rio Verde and Montividiu). The magnitude of these reductions was 905 kg ha^{-1} in Rio Verde and 1,879 kg ha^{-1} in Montividiu. These results demonstrate that the adoption of this spacing can cause damage to the sorghum producer, contrary to theories that advocate greater efficiency in capturing solar radiation with the use of the spacing in question. This is supported by FROMME et al. (2012), who emphasized that when choosing hybrids, plant population and row spacing can have a significant impact on grain sorghum yield.

Table 3. Thousand grain weight and grain yield of grain sorghum plants cultivated in two row spacings with or without nitrogen topdressing.

Topdressing	Spacing (m)					
	0.50	0.25x0.75	Means	0.50	0.25x0.75	Means
	Thousand grain weight (g)			Grain yield (kg ha^{-1})		
			Rio Verde (Brazil)			
90 N	25.42	23.90	24.66	5,639	4,646	5,142 a
0 N	25.97	25.50	25.73	4,843	4,026	4,435 b
Means	25.69	24.70		5,241 A	4,336 B	
CV (%)		10.69			11.65	
			Montividiu (Brazil)			
90 N	23.13	27.10	26.62	6,963	4,774	5,868
0 N	25.13	21.97	23.55	6,260	4,691	5,475
Means	25.63	24.53		6,611 A	4,732 B	
CV (%)		14.48			15.08	

Means followed by different lowercases, in the same column, and uppercases, in the same row, are significantly different by Tukey's test (*p≤0.05*). CV (%): coefficient of variation.

The use of N topdressing in sorghum increased the grain yield only in Rio Verde (Table 3). In this location, the application of 90 kg ha^{-1} N as urea when sorghum plants had four fully developed leaves resulted in an average increase of 707 kg ha^{-1} in grain yield. According to MORTATE et al. (2020), this element is required in greater amounts by sorghum plants and significantly influences grain yield.

The lack of response of grain yield to N topdressing verified in Montividiu indicates that more research is needed to evaluate other factors (doses, sources, application stages, hybrid responses, soil fertility, among others) that may influence the sorghum response to this nutrient. Furthermore, according to FONTES et al. (2017), sorghum response to nitrogen fertilization depends on the predecessor crop, thus being influenced by the production environment (OBOUR et al. 2022). Thus, from agronomic evaluations in the field, it is possible to identify more responsive environments that make it possible to maximize grain yield and thus provide greater

income in agricultural production systems with sorghum cultivation in the *Cerrado* (SANTOS et al. 2022).

Moreover, when analyzing the results obtained in the present study, it becomes evident that management practices should be approached in a multidisciplinary manner (ROCHA et al. 2020), since attempts to modify planting adjustments may lead to different responses from the standpoint of plant nutrition (nitrogen fertilization). Through adjustments related to seeding density or nitrogen supply to the crop, it may be possible to observe improvements in developmental parameters and impacts on sorghum yield. These factors may also influence other aspects of the crop, such as the potential for cultural weed control (BRAZ et al. 2019).

CONCLUSION

The double-row spacing reduced the grain yield at both locations, unlike the traditional spacing.

The Buster hybrid responded to N topdressing only in Rio Verde, without any influence from the plant arrangement.

The double row spacing did not influence the height and thousand-grain weight of grain sorghum plants.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Weverton Ferreira Santos, Alessandro Guerra da Silva and Sergio de Oliveira Procópio; software and validation, Weverton Ferreira Santos, Alessandro Guerra da Silva, Sergio de Oliveira Procópio and Guilherme Braga Pereira Braz; investigation, Weverton Ferreira Santos, Alessandro Guerra da Silva, Sergio de Oliveira Procópio, Guilherme Braga Pereira Braz and Adriano Jakelaitis; resources and data curation, Weverton Ferreira Santos, Rafael Lopes Santos Rodrigues and John Lennon Basílio da Costa; writing-original draft preparation, Weverton Ferreira Santos; writing-review and editing, Alessandro Guerra da Silva, Sergio de Oliveira Procópio, Guilherme Braga Pereira Braz and Adriano Jakelaitis; visualization, Weverton Ferreira Santos, Alessandro Guerra da Silva, Sergio de Oliveira Procópio and Guilherme Braga Pereira Braz; supervision, Alessandro Guerra da Silva and Sergio de Oliveira Procópio; project administration, Alessandro Guerra da Silva and Sergio de Oliveira Procópio; funding acquisition, Alessandro Guerra da Silva. All authors have read and agreed to the published version of the manuscript.

FUNDING

This work was not supported by any funding agency.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable for studies not involving humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

ACKNOWLEDGEMENTS

The authors would like to thank the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) and the *Fundação de Amparo à Pesquisa do Estado de Goiás* (FAPEG).

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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