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What factors influence the density of the giant African snail in a city in the Neotropics?

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Abstract

The giant African land snail, *Lissachatina fulica* (Bowdich 1822), has expanded its distribution throughout the tropics from its native region in Africa over the past 200 years and is a common species in urban environments. Multiple factors are associated with the presence and density of these species, and untangling the contribution of these factors is important in developing control strategies for this invasive species. The African Snail density was estimated in 1,056 sampling plots in Cali Colombia, and this variable was related to weather, microhabitat and habitat structure. This study indicated that the density of this species is mainly affected by climatic conditions, followed by habitat structural variables, and lastly by microclimatic characteristics. The strong El Niño Southern Oscillation (ENSO) during the period of this study significantly impacted the density of the snail through physiological and behavioral mechanisms, such as aestivation, physiological stress, and altered activity levels. The structure of the habitat also plays a crucial role, with higher densities observed in areas with high Normalized Difference Building Index (NDBI) values, likely due to the availability of calcium-rich substrates. The findings of this study highlight the detrimental effect of ENSO on the population density of the giant African land snail, but the resilience of the species suggests it will continue to thrive in specific urban habitats despite climatic challenges.

Key words: Invasive species, density, climatic conditions, habitat structure, urban environments, microenvironment, El Niño Southern Oscillation (ENSO).

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¿Qué factores influyen en la densidad del caracol gigante africano en una ciudad del Neotrópico?

Resumen

El caracol gigante africano, *Lissachatina fulica* (Bowdich 1822), ha expandido su distribución a lo largo de los trópicos desde su región nativa en África durante los últimos 200 años y es una especie común en entornos urbanos. Múltiples factores están asociados con la presencia y densidad de esta especie, y desenredar la contribución de estos factores es importante para desarrollar estrategias de control de esta especie invasora. Estimamos la densidad del caracol africano en 1,056 parcelas de muestreo en Cali, Colombia, y relacionamos esta variable con el clima, el microhábitat y la estructura del hábitat. Nuestro estudio indicó que la densidad de esta especie está afectada principalmente por las condiciones climáticas, seguida por las variables estructurales del hábitat y, por último, por las características microclimáticas. La fuerte Oscilación del Sur de El Niño (ENSO) durante nuestro período de estudio afecto negativamente la densidad de los caracoles a través de mecanismos fisiológicos y conductuales, como la estivación, el estrés fisiológico y los niveles de actividad alterados. La estructura del hábitat también jugo un papel crucial, con mayores densidades observadas en áreas con altos valores del Índice de Diferencia Normalizada de Construcción (NDBI), probablemente debido a la disponibilidad de sustratos ricos en calcio. Nuestros hallazgos destacan el efecto perjudicial de ENSO sobre la densidad poblacional del caracol africano, pero la resiliencia de la especie sugiere que continuará prosperando en hábitats urbanos específicos a pesar de los desafíos climáticos.

Palabras Claves: Especies invasoras, densidad, condiciones climáticas, estructura del hábitat, ambientes urbanos, ENSO.

Introduction

The giant African land snail, *Lissachatina fulica* (Bowdich 1822), has expanded its distribution across the tropics from its native region in Africa over the past 200 years (Lowe et al., 2004). This expansion is mainly due to human-mediated introduction processes, through the pet trade and accidental transport in cargo (RAUT & BARKER, 2002; MARTÍNEZ-ESCARBASSIERE *et al.*, 2008). The International Union for Conservation of Nature (IUCN) (LOWE *et al.*, 2004) has listed this species among the 100 most dangerous invasive species in the world. This designation is due to a combination of factors related to its natural history, including a high reproductive rate, physiological ability to withstand climatic change, few natural predators, wide range of food resources, and a high rate of consumption of plant material (PRASAD *et al.*, 2004; SILVA *et al.*, 2022; BHATTACHARYYA *et al.*, 2014).

Land snails are highly sensitive to environmental conditions (NICOLAI & ANSART, 2017; COUFAL *et al.*, 2021, and multiple factors, both climatic and habitat structure, interact with each other to influence their density (RANDOLPH, 1973; MARTIN & SOMMER, 2004; WEHNER *et al.*, 2019). Climatic factors are important because snails are ectothermic organisms whose metabolic rates depend on external temperatures (WEHNER *et al.*, 2021; ERKANO, 2021), and, in addition, high humidity is essential to prevent desiccation and facilitate movement and feeding (RICKARDS, 2012; SCHWEIZER *et al.*, 2019). Also, precipitation patterns influence the availability of moist microhabitats that are preferred by many snail species (KEMENCEI *et al.*, 2014; ČILIAK *et al.*, 2024). Consequently, climate change is expected to further affect snail populations by altering their habitats and the availability of essential resources (ČILIAK *et al.*, 2024).

On the other hand, the structural characteristics of the habitat also have a large effect on land snail density of (MIN *et al.*, 2022). A habitat with complex vegetation structure that favors higher snail density not only provides food but also natural shelters essential for their survival (GHEOCA *et al.*, 2023). Furthermore, the quality of the soil, including its composition and moisture content, influences the availability of essential nutrients such as calcium (MIN *et al.*, 2022). Studies have shown that soil conditions significantly alter snail populations, affecting their abundance (TESLES *et al.*, 2022).

Specifically for the giant African land snail, it has been found that population density at the regional level is influenced by environmental factors, particularly temperature and precipitation. For example, higher densities are found in regions with moderate temperatures and high humidity, (PATIŇO-MONTOYA *et al.*, 2022). Another important factor is the availability of food resources. This species is a generalist herbivore, feeding on a wide range of plant species. Areas with abundant vegetation exhibit particularly high densities (DICKENS, 2016). In this study, the aim is to clarify whether structural habitat conditions, climate or microclimate variables modulate the density of the giant African land snail in a Neotropical urban environment. It is important to understand the contribution of these factors in order to build strategies to control this invasive species. The fact that weather variables will modulate the density of African snails is hypothesized in this study, and, in the last part of the study, it is particularly predicted that the occurrence of El Niňo–Southern Oscillation (ENSO) which generated an increase in the average temperature in Cali during the sampling period, will affect negatively the density of this species.

Materials and Methods

Fieldwork was conducted from May 2023 to April 2024 in the urban area of the city of Cali Colombia (3°24′56"N, 76°30'10"W) (Figure 1). Cali is the capital of the Department of Valle del Cauca, located in the valley of the Cauca River in the southwest of the country. The topography is mostly flat surface, and the urbanized areas of Cali are estimated to be 123 km2 with 2,174,660 inhabitants (SHIRAISHI, 2022). According to the Holdridge system, this city is located in the Tropical Dry Forest (bs-T) life zone (GARCÉS-RESTREPO *et al*., 2016). The average temperature is 24.1°C, the average relative humidity is 73% and the average annual rainfall is 1471 mm, with two periods of maximum precipitation, one between March and May and another from September to November (MUÑOZ *et al*., 2007).

A total of 88 sampling plots (200 m2) per month were randomly located in: sidewalks, river banks or wetlands, private gardens, public gardens, parks, road separators, wastelands and sports areas, for a total of 1056 sampling plots (Figure 1). Giant African land snails were searched for in each sampling plot, visually inspecting likely habitats such as under logs, rocks, leaf litter, and wet vegetation (COPPOLINO, 2010), between 5 a.m. and 10 p.m. Temperature and humidity were measured in each sampling plot using weather Stations as an approach to measure microclimatic conditions. NDBI and NDVI were downloaded from (https://idesc.cali.gov.co/geovisor.php) and climate variables were collected from the regional environmental authority (https://portal-hidroclimatologico.cvc.gov.co/).

To explore the variation in the density of the giant African land snail in Cali Colombia, a Principal Component Analysis of Correlation (PCA) was carried out (Table 1). The variables ENSO and habitat type were treated as dummy variables. The variation was represented in a Cartesian space defined by habitat, climate and microclimate variables. The PCA and graphical representation was developed with the FactoMineR (Lê et al 2008) and factoextra (Kassambara and Mundt 2020) packages in RStudio 4.1.0.

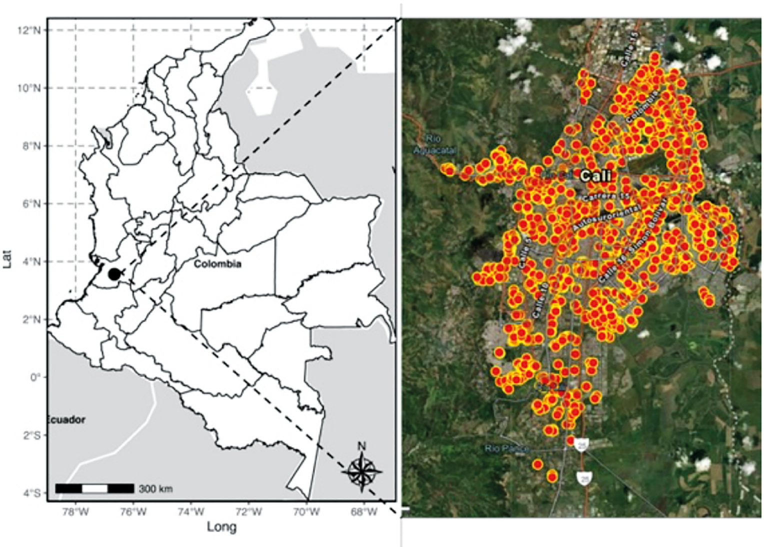

Figure. 1. Geographic location of the city of Cali and sampling plots in the urban habitat.

Table 1. Explanation of variables used in the principal component analysis.

Type	Variable	Description
Habitat structure	Normalized Difference Built-up Index (NDBI)	It is a remote sensing index used to identify and analyze urban and built areas from satellite images. The NDBI takes advantage of the difference in reflectance values between the Near-Infrared (NIR) and Shortwave Infrared (SWIR) spectral bands. This index ranges from -1 to 1, where higher values indicate more built areas
	Normalized Difference Vegetation Index (NDVI)	It is a widely used remote sensing index that measures and monitors vegetation health and density. NDVI is calculated using the difference between the Near-Infrared (NIR) and Red spectral bands, which are captured by satellite sensors.
	Habitat type	Each sampling plot was classified in eight categories of green urban areas accordingly to location, use and function (Albuquerque et al., 2008; Núñez, 2021; Romero-Vargas et al., 2022). Category 1 by Sidewalk, Category 2 River or wetland edge, Category 3 private garden, Category 4 public garden, Category 5 Park, Category 6 road separator, Category 7 wasteland lot, Category 8 sports area
Microclimate	Microclimate average temperature (Temp_micro)	Average temperature in the sample plot measured a meteorological Stations
	Macroclimate average humidity (Hum_micro)	Humidity in the sample plot measured by meteorological Stations
Weather	Macroclimate average temperature (Temp_mean_macro)	Average temperature in the area according to climatological system (https://portal-hidroclimatologico.cvc.gov.co/)
	Macroclimate average humidity (Hum_mean_macro)	Average humidity of the area according to climatological system (https://portal-hidroclimatologico.cvc.gov.co/)
	Macroclimate average precipitation (Precip_mean_macro)	Monthly precipitation in the area according to climatological system (https://portal-hidroclimatologico.cvc.gov.co/)
	ENSO	Occurrence or not of El Niño–Southern Oscillation (ENSO)

Results

Giant African land snails were found in 452 sampling plots (43% of occurrence). For these records, the mean density was 0,036 ± 0,005 ind m-2 (360 ± 50 ind Ha-1). The first two components of the PCA explained only 31,9% of the variance of environmental data. To reach more than 80% of the explanation of variance it is necessary to include up to the fifth component (Table 2). For the first component ENSO and the mean humidity variables had the highest contributions. The sample plots with highest density were distributed in the space defined by PC1 and PC2 with greater frequency in the upper right part of the PC2 axis. This pattern suggests that density is negatively associated with the occurrence of El Niño–Southern Oscillation (ENSO) (Figure 2). This trend was also observed in Figure 3, where the density during the period without the occurrence of the El Niño–Southern Oscillation was higher than that presented during the occurrence of this climatic anomaly.

Table 2. Principal Component Analysis (PCA) of correlation with the values of the variables Climate, Microclimate and Habitat structure of the locations sampled in Cali.

Principal Component	Eigenvalue	% Variance	Cumulative variance percent
PC1	1,94	24,29	24,29
PC2	1,85	23,11	47,40
PC3	1,32	16,48	63,87
PC4	1,08	13,43	77,30
PC5	0,72	9,04	86,34
PC6	0,53	6,56	92,90
PC7	0,41	5,14	98,05
PC8	0,16	1,95	100,00

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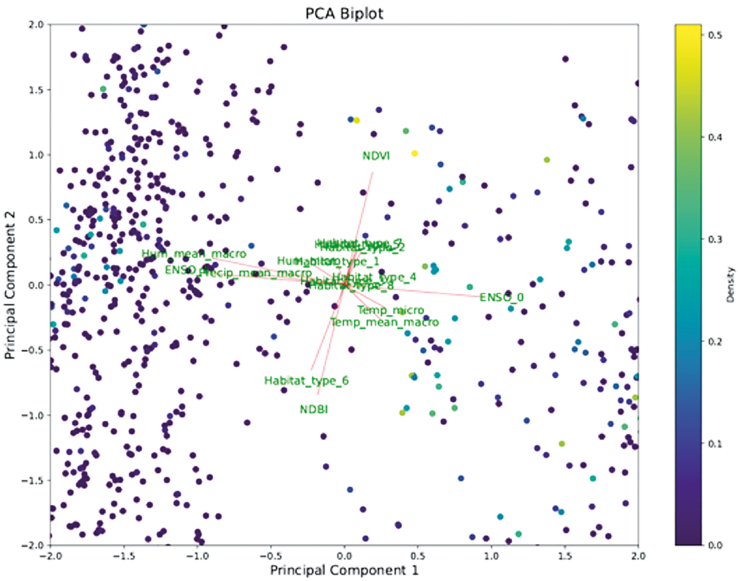

Figure 2. Principal Component Analysis (PCA) with the values of the variables Macroclimate, Microclimate and Habitat structure of the sampled locations in Cali. Each point represents a location and its color represents the density of giant African land snails.

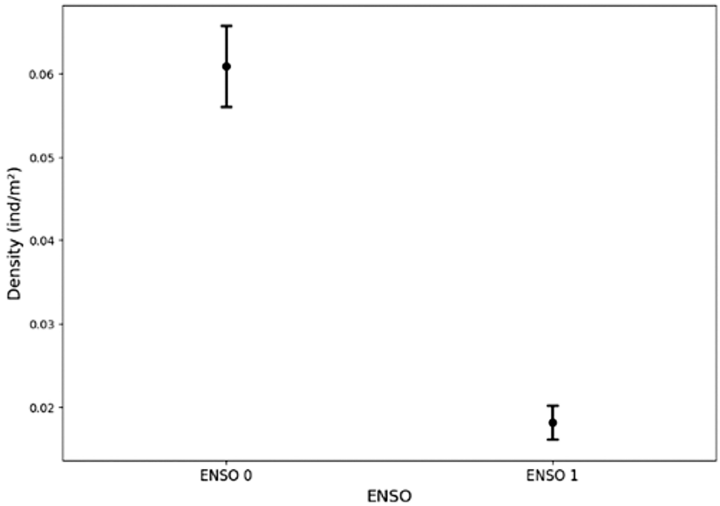

Figure 3. Density of giant African land snails in the period without and with the Occurrence of El Niño–Southern Oscillation (ENSO). Error bars indicate standard error

As for the second component, the Normalized Difference Built Index and the Normalized Difference Vegetation Density Index had the most important contribution. Density shows a positive and significant correlation with NDBI values (Pearson=0.062, p-value=0.043), indicating that a larger built area is associated with a higher density of Giant African land snails (Figure 4, panel a). In the case of Soil and Vegetation the vegetation density index (NDVI), the relationship was negative (Pearson=-0.074, p-value=0.016), and a higher density of giant African land snails was observed in areas with less vegetation (Figure 4, panel b).

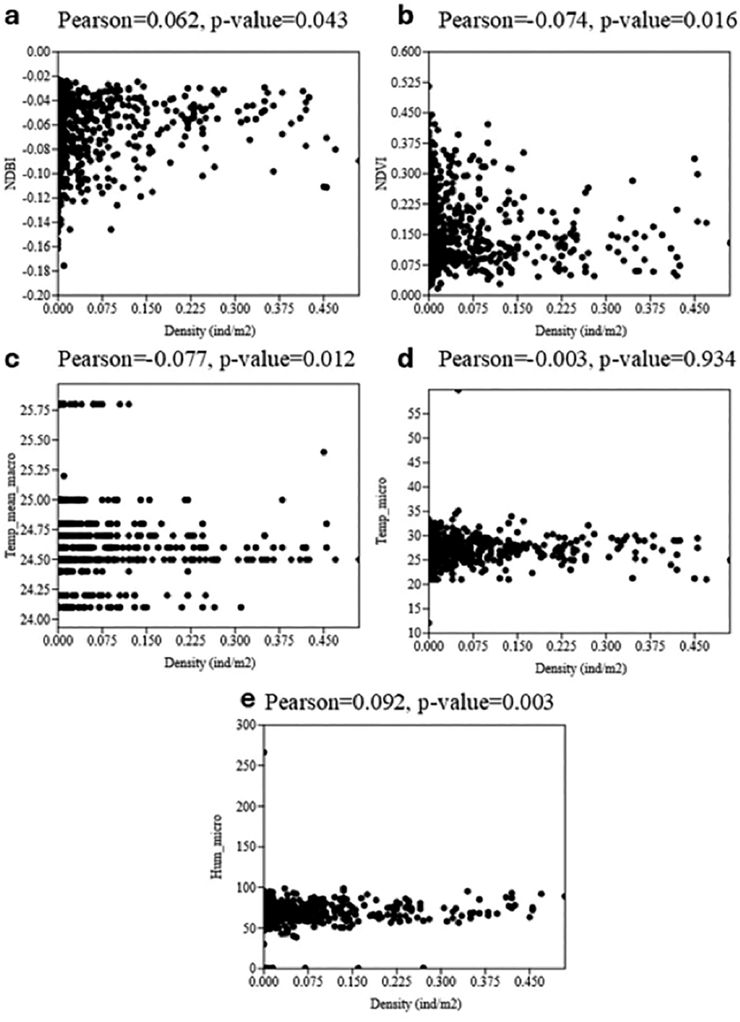

Figure 4. Correlation of meteorological and climate variables with giant African land Snail density showing a contribution to PCA analysis with African Snail density

For the third component, mean macro temperature, sidewalk habitat and park habitat exhibited the greatest contribution. Ambient temperature shows a significant negative correlation (Pearson=-0.077, p-value=0.012), suggesting that snail density increases in areas with lower ambient temperatures (Figure 4, panel c). On the other hand, the two habitat types referred exhibit lower density compared to other habitats such as public or private gardens (Figure 5). The next component presents temperature and humidity of the microclimate as the variables with the greatest contribution to the variance. The temperature of the Microclimate exhibits a negative relationship with density (Pearson=-0.003, p-value=0.934), which indicates a higher density in microclimates with lower temperatures (Figure 4, panel d). Additionally, microenvironmental humidity shows a positive correlation with density (Pearson=0.092, p-value=0.003) (Figure 4, panel e). Finally, for the fifth component the sidewalk and wasteland variables had the largest contributions to the variance. Both habitats exhibit a low density compared to other habitats (Figure 5).

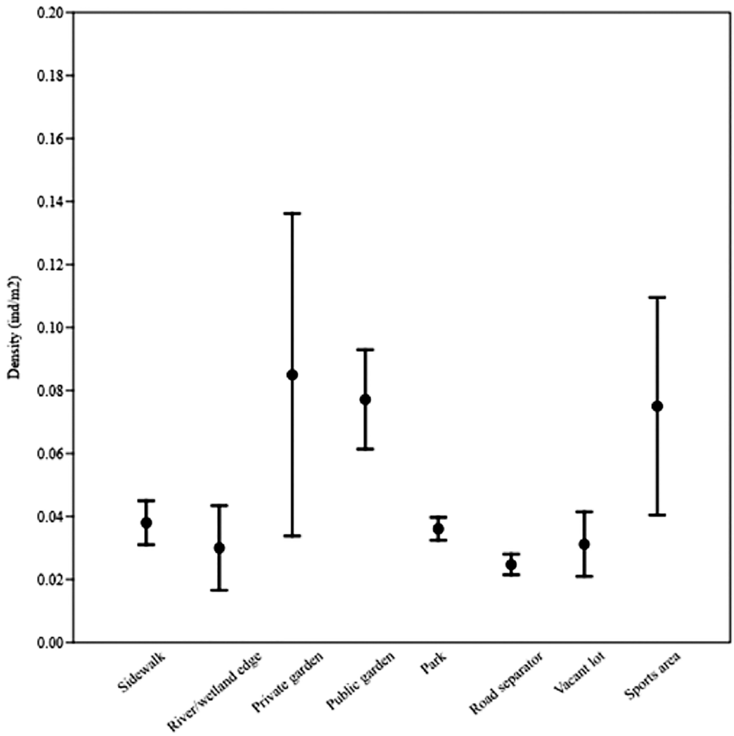

Figure 5. Density of giant African land snails in the different types of habitats in Cali. Error bars indicate standard error.

Discussion

Unraveling the factors that contribute most to the variation in the density of the giant African land snail is complicated due to the interaction of climatic processes, microenvironmental conditions, and habitat structure that influence this characteristic population (SILVA *et al.*, 2014; DICKENS *et al.*, 2018; PATIÑO-MONTOYA *et al.*, 2022). The results of this study indicate that the density of the giant African land snail in the city of Cali was primarily affected by climatic conditions, secondly by structural habitat variables, and thirdly by microclimatic characteristics.

It was argued that the high effect of the climatic variables was associated with the occurrence of a strong El Niño Southern Oscillation (ENSO) during the study. The start of the warm phase of ENSO (El Niño) was predicted for the city of Cali for July 2023, reaching the highest temperatures and low precipitation in the region among November 2023 and April 2024 (LI *et al.*, 2023). In fact, the high temperatures reached during that period broke historical records (RAGHURAMAN *et al.*, 2024). High temperatures can significantly affect density through several physiological and behavioral mechanisms: 1. temperatures above 28°C can initiate aestivation in African snails, interrupting reproductive cycles (SHARMA & DICKENS, 2018). 2. extreme temperatures lead to physiological stress (BENBELLIL-TAFOUGHALTET & KOENE, 2015), leading to decreased egg fertility and viability (SALVADOR & TOMOTANI, 2024). 3. Finally, high temperatures alter the behavior of land snails, making them less active and reducing their nesting frequency (SALVADOR & TOMOTANI, 2024).

The structure of the habitat also affects African land snail density. This study reveals an increase in density in areas with high NDBI values, which may be associated with the availability of calcium-rich substrates (SKELDON *et al.*, 2007). Concrete has been considered a source of calcium for land snails in urban environments (BARKER, 2001). This behavior has been reported particularly in the giant African land snail which scrapes concrete surfaces to obtain the calcium necessary for shell growth (RAUT & BARKER, 2002). Therefore, areas with a high NDBI contain high availability of calcium which is necessary for growth and reproduction of the giant African land snail. Dense vegetation offers protection from predators and harsh environmental conditions, creating a more stable microhabitat (VIJAYAN, 2020). However, the probability of capture decreases in areas of complex vegetation, which could ultimately affect the estimated density in these areas (BARKER, 2001).

The results of this study indicate that public and private gardens and sports areas are the habitats with the highest density of giant African land snails. However, understanding this pattern is complicated and these results may be influenced by the amount of calcium available, the probability of capture, or even by the horticultural practices carried out in these areas. Finally, microenvironmental conditions also affect the giant African land snail density. Soil pH, moisture, and calcium content have been reported as characteristics that significantly affect the land snail (DICKENS *et al.*, 2017; 2018). In addition, the presence of organic matter and leaf litter provides both food and shelter, improving habitat suitability for these snails (GHEOCA *et al.*, 2023).

It can be concluded that there are many factors that affect the density of this species in this urban environment. However, the deleterious effect of El Niño Southern Oscillation (ENSO) on the population density of this species is highlighted. Perhaps, this result could be considered the only positive effect at an ecological level that is being generated by the strong climatic oscillations caused by climate change. However, the great resilience that this species presents will allow it to continue developing in specific habitats within cities despite the current climatic conditions. Therefore, it is important to maintain control actions for this species, especially because of its profound repercussions on human health.

Authors contribution

Mario F. Garcés-Restrepo: study design, data collection, data analysis, interpretation of results, writing initial version, approval final version.

Alan Giraldo: conceptualization of the research, design of the study (leader), interpretation of results, obtaining funds, review and editing of initial version, review and editing of final version, approval final version.

Declaration of conflict of interest

The authors declare that there are no financial or other conflicts of interest that could indicate that this research has been biased in any way.

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