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Nutritional status of southern highbush blueberry cultivars under tropical climate conditions of Central Brazil

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Abstract
Global blueberry production has been increasing annually. The cultivation area in Brazil has expanded with the introduction of new low-chill cultivars, particularly those from the Southern Highbush group. Assessing the nutritional status of plants from different cultivars is essential for successful cultivation. In this context, the objective of this study was to evaluate the nutritional status of Southern Highbush blueberry cultivars (Biloxi and Emerald) under tropical climate conditions of Brasília, Distrito Federal, Brazil. The experiment was conducted in 2023 and 2024 at the Fruit Production Sector of the Biology Experimental Station (EEB) of the University of Brasília (UnB). The region's climate is classified as Aw, tropical savanna, with dry winters and rainy summers, according to the Koppen-Geiger classification. The experiment was conducted in a randomized block design, with 10 replications and 10 plants per experimental unit, totaling 200 plants. The treatments evaluated consisted of two cultivars: Emerald and Biloxi. Leaves were analyzed for nutrient contents: macronutrients included nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), expressed in grams per kilogram (g kg^{-1}); and micronutrient contents included boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), expressed in milligrams per kilogram (mg kg^{-1}). The cultivars had a significant ($p < 0.01$) effect on leaf macronutrient (N, P, K, Ca, Mg, and S) and micronutrient (Fe, Mn, Cu, Zn, and B) contents in both years evaluated. The cultivar Emerald exhibited higher accumulation of N, P, Zn, and Cu, whereas the cultivar Biloxi showed greater accumulation of K, Ca, Mg, S, Fe, Mn, and B in leaf tissues.

Keywords: biloxi, leaf nutrient content, emerald, southern highbush, *Vaccinium spp*.

Introduction

The world's annual blueberry (*Vaccinium* spp) production has been increasing to meet the growing demand. According to the International Blueberry Organization (IBO), global fresh blueberry production reached approximately 1,302,000 Mg in 2023, with the majority produced by China, the United States, Peru, and Chile (IBO, 2024). Blueberry cultivation in Brazil is not well-documented, and official data on these crops remain scarce.

Blueberry crop areas in Brazil are still predominantly located in the states of Rio Grande do Sul, Paraná, Santa Catarina, and some high-altitude regions of São Paulo and Minas Gerais (Medina et al., 2018). However, the introduction of new low-chill cultivars, primarily those from the Southern Highbush group, has boosted blueberry production in the country by enabling cultivation in regions without winter chilling (Cantuarias-Avilés et al., 2014). Cultivars adapted to most tropical and subtropical microclimates of Brazil include Biloxi, which can be grown even in hot climate regions (Lima et al., 2020; Murakami et al. 2023), and Emerald, which exhibits good performance in regions without temperatures below 7.2 °C (Medina et al., 2018).

However, blueberry cultivars have varied environmental response and adaptation characteristics (Pinzón-Sandoval et al., 2023). Thus, growing these cultivars in Brazil requires studies on their adaptations to diverse climate and management conditions. According to Medeiros et al. (2018), assessing the performance of cultivars in the environment of interest is an efficient method for selecting the genotypes better adapted to cultivation. Production dynamics, fruit quality, and plant growth of these cultivars have been extensively studied; however, few studies in the literature have addressed the nutritional status of blueberry leaves.

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Assessing the nutritional status of plants from different cultivars is essential for successful cultivation in modern competitive agriculture, as it provides an effective technique to detect nutritional imbalances, enables the rationalization of input application, assists in fertilizer recommendations, and reduces misdiagnoses of nutrient deficiency or excess (Conceição et al. 2024). However, according to Silva et al. (2024), references for blueberry leaf nutrient contents are scarce, particularly for new cultivars grown in tropical regions. Moreover, nutrient demand varies depending on the plant species, cultivar, and expected yields (Pinzón-Sandoval et al., 2023).

In this context, the objective of this study was to evaluate the nutritional status of the Southern Highbush blueberry cultivars Biloxi and Emerald under tropical climate conditions of Brasília, Distrito Federal, Brazil.

Material and Methods

The experiment was conducted in 2023 and 2024 at the Fruit Production Sector of the Biology Experimental Station (EEB) of the University of Brasília (UnB), in Brasília, Distrito Federal, Brazil (15°44'24''S and 47°52'12''W). The region's climate was classified as Aw, tropical savanna, with dry winters and rainy summers, according to the Köppen-Geiger classification (Cardoso et al., 2014). Mean monthly temperatures and rainfall depths during the experimental period were monitored using a meteorological station of the Brazilian National Institute of Meteorology (INMET, 83377) (**Figure 1**).

The blueberry cultivars evaluated were Emerald and Biloxi, which belong to the Southern Highbush group. In the study region, these two cultivars are evergreen, i.e., do not enter a dormancy stage. Seedlings of both cultivars were developed through micropropagation and planted at the same age on November 21, 2021. Seedlings were selected prior to planting, with those exhibiting the same developmental standard (height, branching, leaf color) being chosen.

The cultivation of both cultivars was carried out in pots using polyethylene bags containing a volume of 60 dm^3 of substrate. The substrate used consisted of 56 liters of unburned rice husks and 4 liters of sphagnum peat, as recommended by Lima (2021) for blueberry cultivation. Pots were arranged in two rows (one per cultivar), spaced 0.40 m apart within rows and 2.5 m between rows. One seedling was planted per pot, resulting in an estimated plant density of 10,000 plants per hectare. The substrate was assessed for its physical and chemical properties at the start of the experiment; the results are presented in **Table 1**.

Pruning was conducted at the end of the 2021–2022, 2022–2023, and 2023–2024 cycles, but with slight differences between cultivars to optimize pruning for each. Severe pruning, involving the cut of all branches to a height of 20 cm (**Figure 2**A) was performed for the cultivar Biloxi, whereas a lighter pruning, retaining more vigorous vegetative branches was applied to the cultivar Emerald (Figure 2B). No plant mortality resulted from pruning due to the pruning type used for each cultivar. Thinning of less vigorous branches was performed 20 days after the onset of sprouting for both cultivars across all production cycles.

Soil fertilizers and irrigation were applied through fertigation, using products that supplied macronutrients and micronutrients at annual equivalent rates of 200 kg ha^{-1} (N), 120 kg ha^{-1} (P_2O_5); 250 kg ha^{-1} (K_2O); 200 kg ha^{-1} (Ca) 120 kg ha^{-1} (Mg); and 150 kg ha^{-1} (SO_4), following recommendations adapted from Lima (2021) for blueberry crops grown in pots with substrate.

Fertigation was performed daily using a drip system with one emitter per plant, providing a mean daily water depth of 2.5 liters per plant. Irrigation was automated with five watering sessions at pre-programed times (08:00, 12:00, 14:00, 16:00, and 18:00 hours). The pH and electrical conductivity of the irrigation water and nutrient solution were monitored using a portable meter (HI9814 pH/EC/TDS).

Both cultivars were fertigated with the same nutrient solution throughout the entire evaluation cycle. Two concentrated solutions were applied, based on the compatibility of fertilizers for dilution. The fertilizers were diluted in separate tanks and injected simultaneously into the irrigation system using a fertilizer injector (HidroFerti

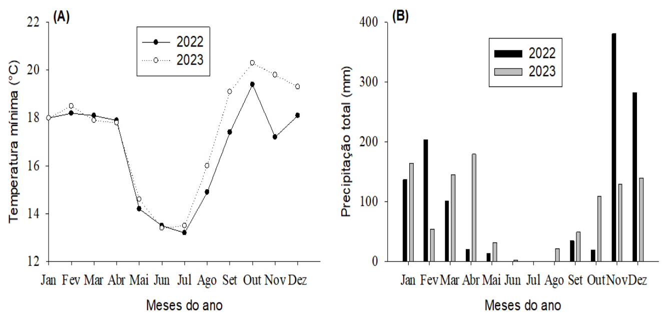

Figure 1. Mean monthly minimum temperatures (°C) (A) and rainfall depths (mm) (B) during the experiment. Brasília, DF, Brazil, 2025.

Table 1. Dry density (DD); total porosity (TP); pH; electrical conductivity (EC); organic matter (OM), and calcium (Ca), magnesium (Mg), and Iron (Fe) contents in the substrate used in the experiment. Brasília, DF, Brazil, 2025

DD	TP	pH	EC	OM	Ca	Mg	Fe
Kg m^{-3}	%	-	mS cm^{-1}		mg L^{-1}		
131.71	85.46	5.56	0.418	224.4	47.4	1.98	0.79

Mini) that enables the mixing of clear irrigation water with nutrient solutions. The same nutrient solution was applied to all plants based on its electrical conductivity. The concentrated solutions were prepared every four days.

The experiment was conducted in a randomized block design, with 10 replications and 10 plants per experimental unit, totaling 200 plants. The treatments evaluated consisted of two cultivars: Emerald and Biloxi.

Leaves were sampled when both cultivars exhibited mature vegetative branches. Five leaves with petiole from each plant were collected from branches in the middle third of the plants, totaling 50 leaves per replication for each treatment (cultivar). The collected leaves were fully expanded, free of diseases, pests or damages, and not from sucker branches. The leaf sampling methodology was adapted from Hart et al. (2006), who described specific procedures for blueberry plants.

After collection, leaves were placed in paper bags, transported to the Fruit Production Laboratory of the University of Brasília, washed with running water and distilled water, and shade-dried on porous paper. They were then dried in a forced-air oven at 65 °C for 72 hours and stored in paper bags enclosed in plastic bags until analysis.

Leaf nutrient contents were determined following the methodology described by Bataglia et al. (1983). Leaves were analyzed for nutrient contents: macronutrients included nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), expressed in grams per kilogram (g kg^{-1}); micronutrients

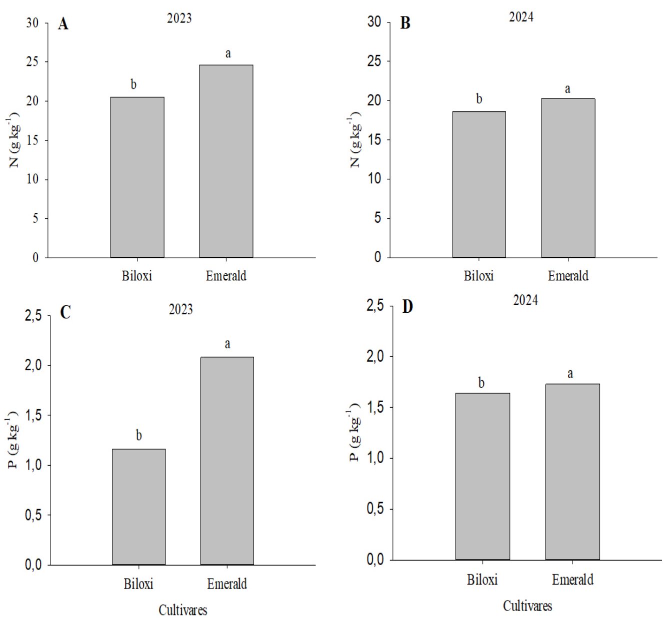

Figure 2. Leaf nitrogen (A and B) and phosphorus (C and D) contents in blueberry plants of the cultivars Biloxi and Emerald in 2023 and 2024. Brasília, DF, Brazil, 2025.

included boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), expressed in milligrams per kilogram (mg kg^{-1}). The obtained data were subjected to analysis of variance and subsequently compared using the Tukey's test ($p < 0.05$), with the statistical program Sisvar (Ferrreira, 2000).

Results and Discussion

The obtained results revealed a significant ($p < 0.01$) effect of cultivars on leaf macronutrient (N, P, K, Ca, Mg, and S) and micronutrient (Fe, Mn, Cu, Zn, and B) contents in blueberry plants in both evaluation years (2023 and 2024). Leaf N contents in blueberry plants of the cultivar Emerald were higher than those of the cultivar Biloxi in both years (Figures 2A and 2B). The results were 24.62 g kg^{-1} (Emerald) and 20.53 g kg^{-1} (Biloxi) in 2023, and 19.24 g kg^{-1} (Emerald) and 18.64 g kg^{-1} (Biloxi) in 2024. Lima et al. (2020) studied the blueberry cultivar Biloxi under similar climate conditions and reported leaf N contents ranging from 24.02 to 25.21 g kg^{-1}.

N leaf contents observed for Emerald and Biloxi in 2023 exceeded the normal range for blueberry leaf tissues (17.6 to 20.0 g kg^{-1}) described by Hart et al. (2006), whereas in 2024, N contents fell within this range. Most N supplied via fertigation was derived from ammoniacal sources (ammonium sulfate and monoammonium phosphate), with a small portion provided by calcium nitrate. This may have contributed to maintaining leaf N contents within or slightly above the normal range for both cultivars. According to Osorio et al. (2020), highbush blueberry (*Vaccinium corymbosum* L.) preferentially absorbs NH_4^+ over NO_3^-. This preference is linked to the adaptation of *V. corymbosum* to its native habitat, the understory of temperate forests, characterized by acidic soils, low temperatures, reduced microbial activity, slow organic matter mineralization, and predominance of $NH4^+$, an inorganic N form (METCALFE et al., 2011).

The cultivar Emerald exhibited the highest leaf P contents in both years compared to Biloxi (Figures 2C and 2D). This result differs from those of Silva et al. (2024), who conducted a nutritional characterization of blueberry plants adapted to hot climates and found higher P leaf contents for Biloxi compared to Emerald. Leaf P contents were 1.16 g kg^{-1} (Biloxi) and 2.08 g kg^{-1} (Emerald) in 2023 (Figure 2C), and 1.64 g kg^{-1} (Biloxi) and 1.76 g kg^{-1} (Emerald) in 2024 (Figure 2D). These results fell within the normal range for blueberry leaf tissues (1 to 4 g kg^{-1}) described by Hart et al. (2006).

In contrast to N and P, leaf K contents were higher for Biloxi compared to Emerald in both years (**Figures 3**A and 3B). Contrasting results were reported by Rivaneira

(2012), who evaluated the leaf mineral composition of different blueberry cultivars and found no significant difference in leaf K contents. Leaf K contents ranged from 3.03 g kg^{-1} (2023) to 4.3 g kg^{-1} (2024) for cultivar Emerald, and from 4.9 g kg^{-1} (2023) to 11.3 g kg^{-1} (2024) for the cultivar Biloxi. In 2023, Emerald plants exhibited K contents below the normal range for the crop (0.41% to 0.70%) described by Hart et al. (2006), whereas Biloxi plants had leaf K contents above this range in 2024.

Similar to K, leaf Ca contents were higher for the cultivar Biloxi in both years (Figures 3C and 3D). However, leaf Ca contents in 2023 and 2024 for this cultivar exceeded the normal range (0.41% to 0.8%) described by Hart et al. (2006) for blueberry plants. These results indicate that leaf Ca content in blueberry plants varies by cultivar. Thus, determining and implementing specific managements to achieve a balanced Ca nutrition for each cultivar is essential for successful blueberry production. Additionally, beyond its functions as a macronutrient, Ca serves as a second messenger in plant cells (Doyle et al., 2021).

Leaf Mg contents showed no statistically significant differences between cultivars in 2023 (**Figures 4**A and 4B), but exhibited differences in 2024, with values of 2.0 g kg^{-1} and 2.5 g kg^{-1} for Emerald and Biloxi, respectively. These results fall within the normal range described by Hart et al. (2006) for leaf Mg in blueberry plants. Leaf S contents for Emerald and Biloxi were 1.0 and 1.6 g kg^{-1} in 2023, and 2.0 g kg^{-1} and 2.6 g kg^{-1} in 2024, respectively (Figures 4C and 4D).

Thus, under the study conditions, plants of the cultivar Biloxi exhibited higher leaf K, Ca, Mg, and S contents (Figures 3A, 3B, 3C, 3D, 4A, 4B, 4C, and 4D), whereas those of the cultivar Emerald showed the highest leaf N and P contents (Figures 2A, 2B, 2C, and 2D), regardless of the evaluation year.

All leaf micronutrient (Fe, Mn, Cu, Zn, and B) contents were significantly affected by cultivars in both years (**Figures 5**A, 5B, 5C, 5D, 6A, 6B, 6C, 6D, 6E, and 6F). Fe contents were higher for Biloxi in both years (Figures 5A and 5B). Fe contents for Biloxi and Emerald were 91.5 and 38.1 mg kg^{-1} in 2023, and 283.3 and 98.8 mg kg^{-1} in 2024, respectively. According to Hart et al. (2006), the normal range for leaf Fe contents in blueberry plants is 61 to 200 mg kg^{-1}. Thus, leaf Fe contents for Biloxi in 2023 were 41.65% above the upper limit of this range, while those for Emerald in 2024 were 37.54% below the lower limit.

The results for leaf copper contents in blueberry plants differed from those for Fe and Mn, with higher Cu accumulation for the cultivar Emerald compared to Biloxi in 2023 (**Figures 6**A and 6B). The values were 5.73 mg kg^{-1} for Biloxi and 7.44 mg kg^{-1} for Emerald, falling within the normal range described by Hart et al. (2006) for blueberry plants. In contrast, no significant differences in leaf Cu contents were observed between cultivars in 2024.

Similar to Cu, leaf Zn contents were higher for Emerald in both years (Figures 6C and 6D). The results were 11.48 mg kg^{-1} for Biloxi and 13.78 mg kg^{-1} for Emerald in 2023, and 12.77 mg kg^{-1} for Biloxi and 18.81 mg kg^{-1} for Emerald in 2024. All leaf Zn contents fell within the normal range described by Hart et al. (2006).

Leaf B contents exhibited similar patterns to those of Fe and Mn, with higher values for the cultivar Biloxi

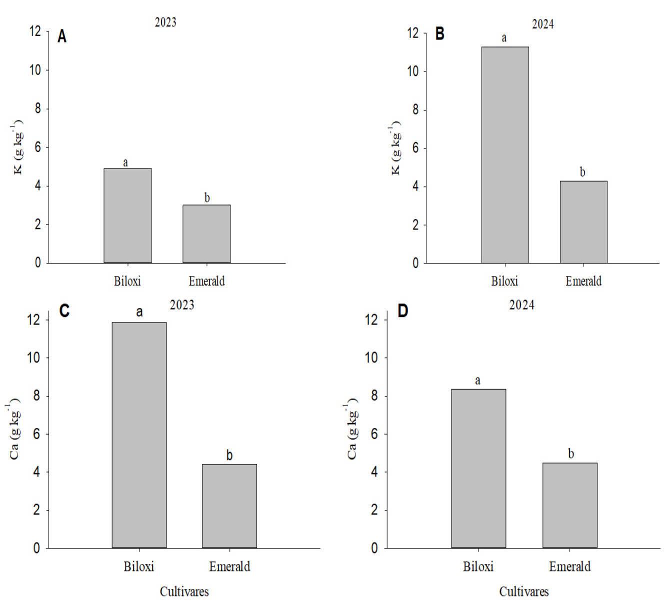

Figure 3. Leaf potassium (A and B) and calcium (C and D) contents in blueberry plants of the cultivars Biloxi and Emerald in 2023 and 2024. Brasília, DF, Brazil, 2025.

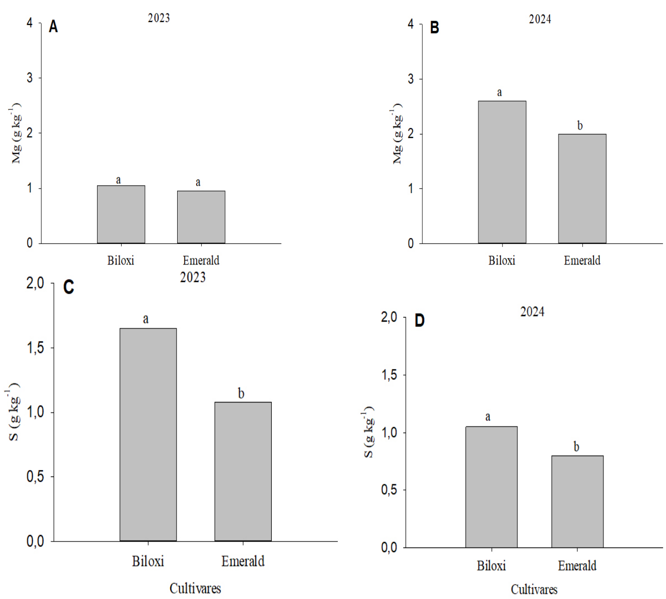

Figure 4. Leaf magnesium (A and B) and sulfur (C and D) contents in blueberry plants of the cultivars Biloxi and Emerald in 2023 and 2024. Brasília, DF, Brazil, 2025

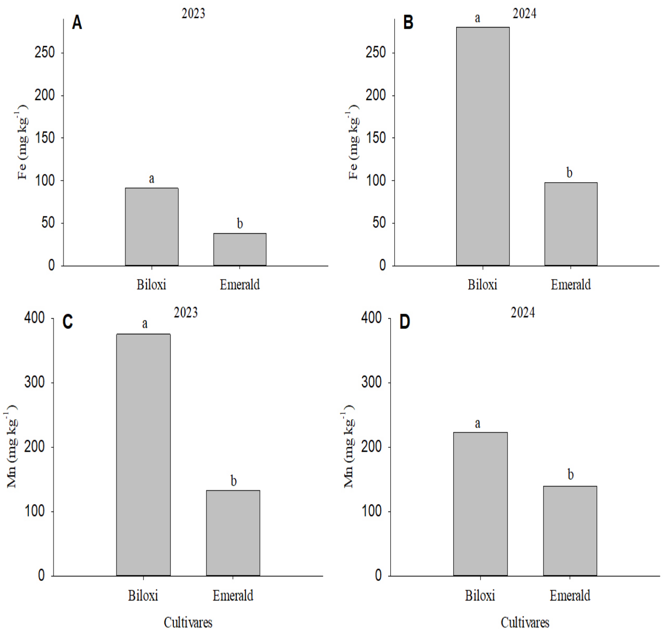

Figure 5. Leaf iron (A and B) and manganese (C and D) contents in blueberry plants of the cultivars Biloxi and Emerald in 2023 and 2024. Brasília, DF, Brazil, 2025.

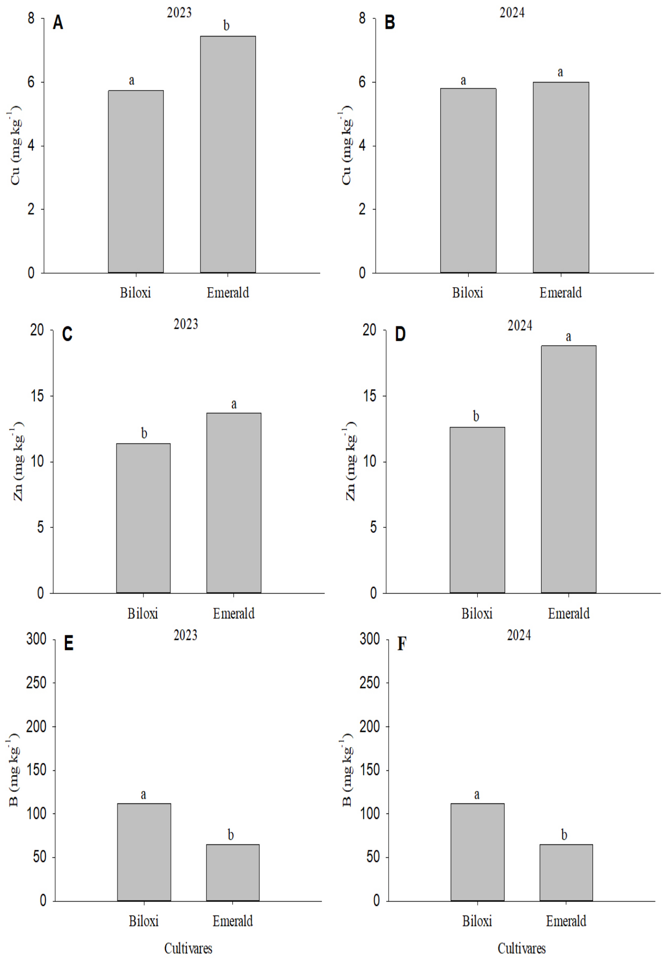

Figure 6. Leaf copper (A and B), zinc (C and D), and boron (A and B) contents in blueberry plants of the cultivars Biloxi and Emerald in 2023 and 2024. Brasília, DF, Brazil, 2025.

(Figures 6E and 6F). In 2023, the results ranged from 91.80 mg kg^{-1} for Emerald to 273.6 mg kg^{-1} for Biloxi, exceeding the normal range (31 to 80 mg kg^{-1}) described by Hart et al. (2006) for blueberry leaf tissues. In 2024, the values were 65.43 mg kg^{-1} (Emerald) and 112.48 mg kg^{-1} (Biloxi); thus, only Emerald exhibited B contents within normal range for blueberry crops.

Critical B limits (low or high) in plant tissues are narrow, and the B requirement range varies widely among species and genotypes; an optimal value for one cultivar may be insufficient or toxic to other species or cultivars (LANDI et al., 2012). Blueberry genotypes have exhibited differences in leaf B accumulation under the same B fertilizer application rate, as reported by Meriño-Gergichevich et al. (2017), who applied a nutrient solution containing 12 mg L^{-1} of boric acid and found 98% higher B accumulation in the cultivar Legacy compared to Brigitta.

Conclusions

Leaf macronutrient (N, P, K, Ca, Mg, S) and micronutrient (B, Cu, Fe, Mn, and Zn) contents were influenced by the Southern Highbush blueberry cultivars Biloxi and Emerald under the tropical climate conditions of Brasília, Distrito Federal, Brazil.

The cultivar Emerald exhibited greater leaf N, P, Zn, and Cu accumulation, whereas the cultivar Biloxi showed higher leaf K, Ca, Mg, S, Fe, Mn, and B accumulation. This suggests that achieving an optimal nutritional status for all these nutrients simultaneously for both cultivars under identical nutritional management is not feasible.

The leaf macronutrient and micronutrient contents accumulated by Biloxi and Emerald plants varied within the same year and across different years. Factors influencing these results include genetics, climate, nutrition, irrigation, pest and disease incidence, and leaf sampling timing. These factors require further investigation to elucidated these variations and to establish optimal nutritional management practices for each cultivar.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.