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ABSTRACT

Cassava (*Manihot esculenta* Crantz) plays a strategic role for food security, agro-industry, and smallholder farming systems in tropical countries. In this context, validating genotypes under diverse field conditions represents a critical step for cultivar recommendation. This study evaluated the agronomic performance of ten sweet cassava genotypes in two contrasting environments of the Goiás Cerrado (Araçu and Porangatu) during the 2020/2021 growing season. A randomized complete block design with three replications was used, each experimental unit consisted of 12 plants, and productive, morphological, and root-quality traits were assessed. Joint analysis of variance revealed significant effects of genotype and location for most traits, with a significant Genotype × Location interaction for root yield and starch yield. Principal component analysis (PCA) indicated positive correlations between root yield and starch yield, as well as between plant height and shoot yield provide a robust basis for identifying superior germplasm. All genotypes exhibited high yield potential, surpassing the regional mean. The Cultivar BRS 429 exhibited superior agronomic performance for most evaluated traits.

Key words: *Manihot esculenta* Crantz, root yield, genotype x environment interaction, principal component analysis, cultivar evaluation.

Desempenho agronômico de genótipos de mandioca de mesa em ambientes contrastantes do Cerrado Goiano

RESUMO

A mandioca apresenta importância estratégica para a segurança alimentar, agroindústria e os sistemas de agricultura familiar em países tropicais. Nesse contexto, a validação de genótipos em condições de campo constitui etapa essencial para a recomendação de cultivares. Este estudo objetivou avaliar o desempenho agronômico de dez genótipos de mandioca de mesa em dois ambientes contrastantes do Cerrado goiano (Araçu e Porangatu), na safra 2020/2021. Utilizou-se o delineamento de blocos casualizados, com três repetições, cada unidade experimental foi constituída por 12 plantas, avaliando-se caracteres produtivos, morfológicos e de qualidade de raízes. A análise de variância conjunta indicou efeitos significativos de genótipo e local para a maioria dos caracteres, com interação Genótipo × Local significativa para a produtividade de raízes. A análise de componentes principais (ACP) evidenciou correlações positivas relevantes entre produtividade de raízes e de amido; e altura de planta e produtividade da parte aérea. Todos os genótipos superaram a média regional, indicando alto potencial produtivo. A cultivar BRS 429 destacou-se pelo desempenho superior e menor sensibilidade ambiental, indicando atributos favoráveis de rendimento e qualidade no Cerrado goiano.

Palavras-chave: *Manihot esculenta* Crantz, produtividade de raízes, interação genótipo x

ambiente, análise de componentes principais, competição de cultivares.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a tropical crop native to South America that plays a central role in food security in developing countries due to its high energy content (Olsen & Schaal 1999). The crop has broad potential for use: its roots are important sources of starch for both human consumption and industrial applications, while the protein- and vitamin-rich aerial parts represent valuable resources for human and animal nutrition (Fernandes et al. 2020).

Cassava roots and leaves contain cyanogenic glycosides that release hydrogen cyanide (HCN) upon tissue disruption. Sweet and bitter cassava are distinguished primarily by the concentration of HCN, for fresh consumption, cassava roots should contain less than 100 mg HCN equivalents kg^{-1} fresh pulp. In contrast, roots exceeding this threshold are suitable for industrial because processing reduces their toxic potential to levels considered safe for human consumption (Borges et al. 2002, Vieira et al. 2022).

Cassava crop is characterized by hardiness, adaptation to low-fertility soils, and tolerance to water deficit, although it responds positively to improved edaphoclimatic conditions (Zebalho et al. 2024). In Brazil, cassava is a strategic crop, strongly integrated into family farming systems and increasingly relevant to agribusiness, particularly in the Central Brazilian Cerrado (Vieira et al. 2018, Vieira et al. 2020). This scenario has intensified the demand for the selection and recommendation of new cassava cultivars.

Validating cultivars across multiple environments is a critical stage in breeding programs, as genotype × environment (G×E) interaction can reduce the predictability of agronomic performance and limit broader recommendations (Ceballos et al. 2021). Recent studies have demonstrated substantial genetic variability for traits such as root yield, plant architecture, and root quality under different cassava production systems (Paz et al. 2020, Ceballos et al. 2021).

In this context, developing an ideotype for sweet cassava requires the integration of technological and sensory attributes. From a technological perspective, desirable traits include high root yield, rapid emergence, plant architecture suitable for mechanization, ease of root detachment, efficient water use, easier peeling of the cortex and periderm, and earliness, among others. From a sensory standpoint, essential characteristics include low HCN content, reduced cooking time (< 30 min), typical organoleptic properties, and soft texture (Fuhrmann et al. 2020, Ceballos et al. 2021, Vieira et al. 2022).

Despite the agronomic and socioeconomic importance of cassava, robust experimental studies on this crop remain scarce in the state of Goiás. Such studies are essential for establishing regional criteria aimed at increasing productivity and local income, particularly given that proper crop management and the selection of adapted genotypes are key factors in reducing yield gaps in sweet cassava production in Brazil (Bexaira et al. 2026).

The present study aimed to evaluate the agronomic performance of sweet cassava genotypes in two contrasting locations in the Cerrado of Goiás.

MATERIALS AND METHODS

The experiments were conducted during the 2020/2021 growing season at two experimental stations with contrasting edaphoclimatic conditions of the Goiana Agency for Technical Assistance, Rural Extension, and Agricultural Research (EMATER-GO). Field trials were conducted at two contrasting locations in the Brazilian Cerrado, the Santa Vitória Experimental Station, Araçu (16°16′ S, 49°44′ W; 716 m), and the Lages Experimental Station, Porangatu (13°18′ S, 49°07′ W; 390 m). Araçu has mean annual rainfall of 1,357 mm and mean maximum and minimum temperatures of 29.4 and 17.0°C, whereas Porangatu receives 1,095 mm of rainfall and has corresponding temperatures of 31.7 and 27.8°C. Both locations are classified as Aw according to the Köppen climate classification.

The two environments differed markedly in their soil physical and chemical properties. The soil in Araçu was more fertile than that in Porangatu, with pH ($CaCl_2$) values of 5.4 and 4.3, and base saturation of 64% and 46%, respectively. Macronutrient levels were also higher in Araçu - P (44 vs. 10 mg dm^{-3}), K (230 vs. 140 mg dm^{-3}), and Ca (4.6 vs. 1.2 cmolc dm^{-3}). Soil texture ranged from 37% clay and 47% sand in Araçu to 42% clay and 36% sand in Porangatu. Organic matter content and potential acidity (H^{+}+Al) were 2.8% and 3.5 cmolc dm^{-3} in Araçu, and 1.3% and 2.4 cmolc dm^{-3} in Porangatu, respectively.

A randomized complete block design with three replications was adopted. Treatments consisted of ten sweet cassava genotypes, five cultivars developed by Embrapa Cerrados (BRS 396, BRS 397, BRS 398, BRS 399, and BRS 429); three local landraces selected by EMATER-GO (Branca Pancinha, Cacau, and Branca de Rio Verde); and the cultivated checks with broad adaptability to the production ecosystems of Goiás (IAPAR 19 and IAC 576-70).

Experimental plots consisted of four rows with eight plants each (totaling 32 plants), spaced 1.00 m between rows and 0.80 m between plants. The evaluation area comprised the 12 central plants from the two inner rows. Crop management followed the technical recommendations for cassava cultivation in the Cerrado (Fialho & Vieira 2013).

The experiments were established on 20 October in Araçu and 28 October in Porangatu, and both were harvested 12 months after planting. The following traits were evaluated: plant height (PH, m), height of first branching (HFB, cm), stem diameter (SD, cm), number of roots per plant (NRP), shoot yield (SY, t ha^{-1}), fresh root yield (RY, t ha^{-1}), harvest index (HI), calculated as the ratio of root mass to total plant mass, cooking time (CT, min) according to BORGES et al. (2002), starch content (SC, %), determined by the hydrostatic balance method (Grossmann & Freitas 1950), and starch yield (StY, t ha^{-1}).

Data were subjected to individual and joint analysis of variance using mixed linear models, with genotypes treated as fixed effects and environments as random effects. Means were grouped using the Scott-Knott test at the 5% significance level (Scott & Knott 1974). Additionally, Principal Component Analysis (PCA) was performed to identify patterns of association among traits and to differentiate genotype performance. The analysis was performed using the grand mean and the correlation matrix of standardized data to eliminate scale effects. The analyses were generated using the statistical software InfoStat (Di Rienzo et al. 2020).

RESULTS AND DISCUSSION

The joint analysis of variance for plant height (PH), height of first branching (HFB), and stem diameter (SD) revealed significant effects of genotype and environment for all variables, except for the genotype effect on SD (Table 1). This result indicates phenotypic variability between the genotypes and the locations considered (Vieira et al. 2018, Paz et al. 2020).

Table 1 - Summary of the joint analysis of variance for plant height (PH), height of first branching (HFB), and stem diameter (SD) in 10 cassava genotypes evaluated in two contrasting Cerrado environments in Goiás during the 2020/2021 growing season.

SV	d.f.	Mean squares			
		PH (m)	HFB (m)		SD (cm)
Local (L)	1	1.99**	0.39*		6.53**
Genotype (G)	9	0.39**	0.61**		0.07^{ns}
GxL	9	0.10^{ns}	0.13**		0.09^{ns}
Residual	35	0.09	0.04		0.07
Mean		2.59	1.01		3.02
CV (%)		11.41	20.79		8.73
Genotype			Araçu	Porangatu	
BRS 429		2.91a	1.56a	1.80a	2.93

Cacau	2.81a	0.81b	0.60c	2.97
BRS 399	2.78a	0.79b	0.80c	3.02
IAPAR 19	2.71a	1.40a	1.20b	2.96
BRS 397	2.64a	0.80b	0.42c	2.95
BRS 396	2.59a	0.90b	0.74c	3.08
Branca Rio Verde	2.59a	1.06b	1.10b	3.23
IAC 576-70	2.57a	0.93b	0.74c	3.07
Branca Pancinha	2.16b	1.40a	0.54c	2.87
BRS 398	2.15b	1.11b	1.21b	3.14

**ns, and * indicate non-significant effects and significance at $p \leq 0.01$ and $p \leq 0.05$, respectively, according to the F test. SV: source of variation; df: degrees of freedom; CV: coefficient of variation. Means followed by the same letter within a column do not differ statistically according to the Scott–Knott test at $p \leq 0.05$.

In contrast, the genotype × environment (G×E) interaction was significant only for HFB, although its phenotypic expression is modulated by environmental conditions Ceballos et al. 2004). This discrepancy can be physiologically explained because branching occurs when flowering-induced by photoperiod-breaks apical dominance (El-Sharkawy 2004).

The overall mean PH was 2.59 m, exceeding the values reported by Ceballos et al. (2004) and Paz et al. (2020), indicating vigorous vegetative growth. According to the Scott–Knott test, BRS 429 was included in the group with the greatest plant height, together with seven other cultivars, whereas Branca Pancinha and BRS 398 exhibited the lowest plant heights (Table 1). No lodging was observed despite the relatively tall plant stature in the experimental areas. For HFB, the G × E interaction revealed contrasting genotype means responses across locations. In Araçu, the highest values were observed for the BRS 429, IAPAR 19, Branca Pancinha cultivars, whereas in Porangatu, the BRS 429 cultivar maintained superior performance, once again standing out compared to the other genotypes.

High mean values for PH, HFB, and SD are important in new cultivars, given the direct influence of these traits on operational field efficiency. From an agronomic perspective, plants with this architecture facilitate mechanized planting and crop management practices, such as weed control, phytosanitary inspections, and pesticide applications. Moreover, greater vegetative growth increases the availability of stem cuttings for propagation and enables the aerial part to be used as a protein source for animal feed, thereby adding value to the production system (Fernandes et al. 2020, Vieira et al. 2020).

For shoot fresh weight (SY), number of roots per plant (NRP), fresh root yield (RY), and harvest index (HI), the analysis of variance revealed significant genotype effects for all variables (Table 2). However, the genotype × environment (G×E) interaction was significant only for RY, indicating differential performance among genotype means across locations, reflecting moderate phenotypic plasticity across locations.

Table 2 - Summary of the joint analysis of variance for shoot yield (SY), number of roots per plant (NRP), root yield (RY), and harvest index (HI) in 10 cassava genotypes evaluated in two contrasting Cerrado environments in Goiás during the 2020/2021 growing season.

SV	d.f.	Mean squares			
		SY (t ha^{-1})	NRP	RY (t ha^{-1})	HI
Local (L)	1	38.66^{ns}	0.84^{ns}	307.00*	0.09*
Genotypes (G)	9	261.74**	10.32*	134.16**	0.02**
G*L	9	43.94^{ns}	4.48^{ns}	129.87**	0.003^{ns}
Residual	35	53.79	3.54	40.00	0.002
Mean		31.52	10.18	34.67	0.53
CV (%)		23.27	18.49	18.24	8.87
Genotype				Araçu Porangatu	

Cacau	41.67a	9.45b	25.95b	25.98b	0.41c
BRS 399	38.46a	11.56a	34.95a	34.94a	0.49b
BRS 397	37.52a	11.81a	39.90a	47.96a	0.52a
BRS 429	32.10b	9.61b	39.58a	39.63a	0.55a
Branca Rio Verde	31.22b	9.48b	38.69a	37.45a	0.53a
IAPAR 19	30.53b	9.28b	30.36b	31.73b	0.52a
BRS 396	30.25b	10.83a	38.42a	37.72a	0.55a
IAC 576-70	29.74b	12.18a	34.15a	35.44a	0.54a
BRS 398	24.27c	8.25b	34.95a	44.35a	0.57a
Branca Pancinha	19.40c	9.39b	29.71b	34.07a	0.59a

ns, ** and *: not significant, significant at $p \leq 0.01$, and significant at $p \leq 0.05$, respectively, according to the F test. SV: Source of Variation; d.f.: degrees of freedom; CV: Coefficient of Variation*;* Means followed by the same letter within the same column belong to the same group, according to the Scott-Knott test, at $p \leq 0.05$.

It is known that this trait is quantitative nature and strongly influenced by the edaphoclimatic conditions of the evaluation locations, which affect the genotype-phenotype relationship, as well as the adaptability and stability of productivity (Vieira et al. 2020, Ceballos et al. 2021). This finding reinforces the need for multi-environment trials to ensure accurate selection.

Conversely, the absence of a significant interaction for SY indicates greater consistency of shoot biomass production across environments. The detected genetic variability for this trait is strategically important, as it enables the selection of genotypes with high potential for forage production. The stability in green biomass supply is essential to support the use of the aerial part as a protein source in animal feeding systems, consolidating the dual-purpose potential of selected cultivars (Fernandes et al. 2020, Ceballo et al. 2021).

Fresh root yield (RY) ranged from 25.95 to 39.90 t ha^{-1} in Araçu and from 25.98 to 47.96 t ha^{-1} in Porangatu (Table 2). At both locations, BRS 397, BRS 398, BRS 399, BRS 396, BRS 429, Branca de Rio Verde, and IAC 576-70 were included in the highest-yielding group, whereas Branca Pancinha stood out only in Porangatu, with no significant differences among the genotypes in the top group in either environment. The yields obtained in this study markedly exceeded the state average (16,02 tha^{-1}, IBGE 2026), highlighting the high productive potential of cassava when grown under adequate management and genetic selection. This result is consistent with recent studies demonstrating that optimization of agronomic factors can substantially increase sweet cassava yields in tropical environments (Bexaira et al. 2026).

Regarding shoot yield (SY), variability was observed, with higher mean values for the genotypes Cacau, BRS 399, and BRS 397 (Table 2). This trait is highly desirable for the sustainability of integrated production systems, as it enables the use of biomass both to produce stem cuttings in subsequent planting cycles and as a protein source for animal feed (Fernandes et al. 2020).

The number of roots per plant (NRP) ranged from 8.25 to 12.18, with the highest values recorded for IAC 576-70, BRS 397, BRS 399, and BRS 396, with no statistical differences among these genotypes (Table 2). The harvest index (HI) ranged from 0.41 to 0.59 (Table 2), values HI above 0.50 indicate physiological efficiency in the translocation of photoassimilates to the roots (Conceição 1987), 80% of the genotypes exceeded this threshold, with Cacau and BRS 399 showing the lowest values.

Regarding technological quality, a significant genotype effect was observed for starch content (SC) and starch yield (StY), indicating exploitable genetic variability (Table 3). The overall mean SC was 29.26%, highlighting the local genotypes Branca Pancinha, Branca de Rio Verde and Cacau, along with IAPAR 19, BRS 429 and IAC 576-70. Although starch content is traditionally considered a secondary trait in sweet cassava breeding, it is directly associated with root texture and final consumer acceptance (Ceballos et al. 2021).

Table 3 - Summary of the joint analysis of variance for starch content (SC), starch yield (StY) and cooking time (CT) of 10 cassava genotypes evaluated in two contrasting Cerrado environments in Goiás during the 2020/2021 growing season.

SV	d.f.	Mean squares			
		SC (%)	StY (t ha^{-1})		CT (min)
Local (L)	1	45.23*	16.95^{ns}		2294.02**
Genotype (G)	9	16.94**	12.02*		11.76^{ns}
G*L	9	4.23^{ns}	12.74*		10.94^{ns}
Residual	35	4.70	4.70		7.10
Mean		29.26	19.67		25.85
CV (%)		7.41	10.19		10.31
Genotype			Araçu	Porangatu	
Branca Pancinha		31.41a	7.80b	10.34a	23.40
Branca Rio Verde		30.95a	12.57a	11.43a	21.86
Cacau		30.35a	8.83b	7.36b	19.42
IAPAR 19		30.11a	9.40a	9.24b	17.47
BRS 429		30.00a	12.06a	11.93a	18.53
IAC 576-70		29.55a	10.01a	10.46a	16.47
BRS 396		28.77b	12.12a	10.61a	20.71
BRS 397		28.23b	9.38a	13.25a	17.37
BRS 398		27.00b	5.64b	11.48a	24.68
BRS 399		26.27b	10.02a	8.75b	17.76

ns, ** and * indicate non-significant effects and significance at p ≤ 0.01 and p ≤ 0.05, respectively, according to the F test. SV: source of variation; df: degrees of freedom; CV: coefficient of variation. Means followed by the same letter within a column do not differ statistically according to the Scott–Knott test at $p \leq 0.05$.

Starch yield (StY) was significantly affected by the genotype × location interaction ($p < 0.05$), whereas the main effect of location was not significant (Table 3). Branca Rio Verde, BRS 429, IAC 576-70, BRS 396, and BRS 397 consistently ranked among the highest-yielding genotypes across both locations. In contrast, IAPAR 19 and BRS 399 performed best only in Araçu, whereas Branca Pancinha and BRS 398 showed superior performance exclusively in Porangatu, confirming the presence of a genotype × environment interaction for StY.

Cooking time (CT) was significantly affected only by location ($p < 0.01$) whereas neither genotype nor the genotype × location interaction was significant (Table 3). Although CT is one of the primary attributes of the culinary quality of sweet cassava and an important selection criterion in cassava breeding programs targeting fresh consumption. The evaluated genotypes exhibited similar performance for this trait, with cooking times ranging from 16.47 min for IAC 576-70 to 24.68 min for BRS 398. All genotypes exhibited CT values below 30 min, the maximum threshold considered acceptable for the commercialization of table cassava in Brazil (Borges et al. 2002, Vieira et al. 2018).

The absence of significant differences among genotypes indicates limited detectable genetic variability, which is consistent with the expectation for germplasm developed targeting fresh consumption. In disparity, contrasting Cerrado environmental effects predominated in the expression of this trait, studies have revealed that this factor varies with soil type, variety, and plant age (Borges et al. 2002). Indeed, although cooking time is genetically controlled, its phenotypic expression is strongly influenced by environmental factors that modify the physicochemical properties of cassava roots, particularly those associated with starch gelatinization and water absorption during cooking (Miranda et al. 2020, Silveira et al. 2021, Bandeira et al. 2024).

Principal Component Analysis (PCA)

The graphical dispersion based on the first two principal components (PC1 and PC2) revealed distinct patterns of trait association and genotype grouping, jointly explaining 64.20% of the cumulative variance (Figure 1).

The first principal component (PC1) captured variability associated with shoot yield (SY) and cooking time (CT), whereas PC2 contrasted root yield (RY) with starch content (SC). This spatial configuration highlights a natural separation between productive and quality-related attributes, thereby reflecting the distinct physiological bases underlying these traits.

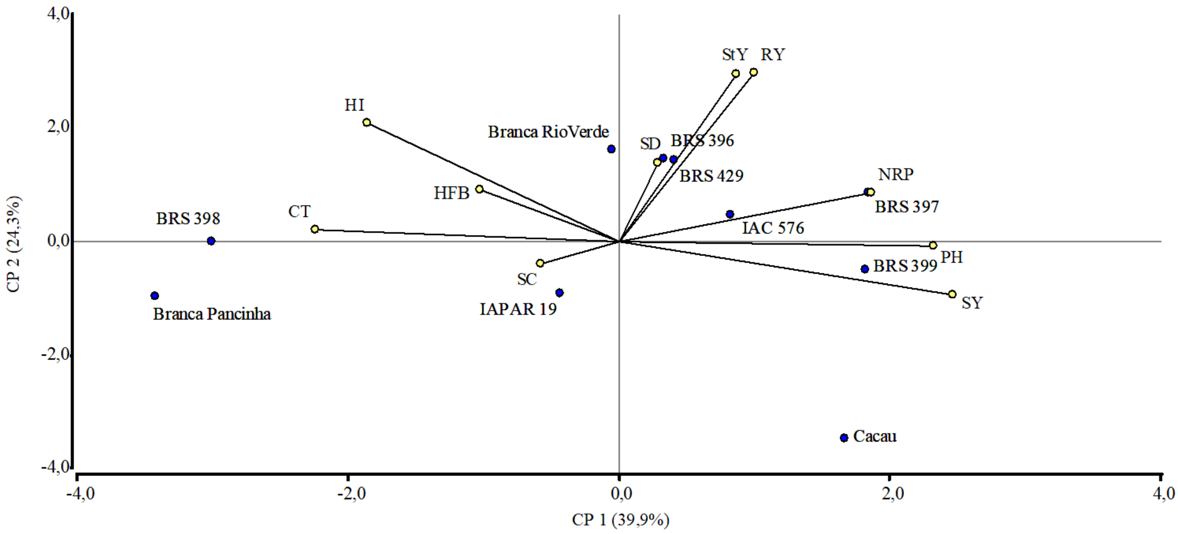

Figure 1 - Biplot of the first two principal components (PC1 and PC2) for ten cassava genotypes evaluated in contrasting Cerrado environments in Goiás (2020/2021 growing season). Variables: plant height (PH), height of first branching (HFB), stem diameter (SD), shoot yield (SY), number of roots per plant (NRP), root yield (RY), harvest index (HI), starch content (SC), cooking time (CT), and starch yield (StY).

Vector analysis, based on the geometric interpretation of the biplot proposed by Di

Rienzo et al. (2020), identified agronomically relevant positive correlations, such as those between RY and starch yield (StY) and between plant height (PH) and SY (Figure 1). Conversely, negative correlations were observed between SC and StY, and between SY and HFB, reinforcing the complexity of simultaneous selection in cassava breeding.

In terms of genotype distribution, the group comprising BRS 429 and BRS 396 stood out due to their strong association with high root yield (RY) and starch yield (StY), whereas BRS 397 was characterized by a high number of roots per plant (NRP). The genotypes BRS 399 and Cacau were associated with greater vegetative vigor, as indicated by higher SY and PH values. In contrast, BRS 398 was positioned in the direction of higher cooking time (CT) and harvest index (HI) values, suggesting possible limitations for the fresh market (Figure 1).

The cultivar Branca Pancinha was associated with quality-related traits, particularly starch content (SC). Finally, the cultivars BRS 429, IAC 576-70, and IAPAR 19 were located near the center of the biplot (Figure 1), indicating a more consistent behavior across contrasting locations of the Cerrado de Goiás.

CONCLUSION

The traits Fresh root yield, starch yield, and first branching height showed significant genotype × location interaction underscores the importance of evaluating sweet cassava genotypes across contrasting locations. BRS 429 exhibited superior agronomic performance for most evaluated traits, whereas BRS 397, BRS 398, BRS 399, BRS 396, Branca de Rio Verde, and IAC 576-70 were among the highest-performing genotypes. Together with the multivariate analyses, these findings provide a basis for identifying superior germplasm and support breeding decisions aimed at developing high-yielding sweet cassava cultivars for the Brazilian Cerrado.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest associated with this publication.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to the conception of the study, data analysis, manuscript preparation, and critical revision, and all authors approved the final version of the manuscript.