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# Agronomic performance of sweet cassava genotypes in contrasting Cerrado environments in Goiás

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1 All genotypes exhibited high yield potential, surpassing the regional mean. Cultivar BRS 429  
2 showed superior performance and lower environmental sensitivity, indicating greater yield  
3 stability and favorable productivity and quality attributes for the Goiás Cerrado.

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

## 6 **RESUMO**

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

21 **Palavras-chave:** *Manihot esculenta* Crantz, produtividade de raízes, interação genótipo x  
22 ambiente, análise de componentes principais, competição de cultivares.

## 23 **INTRODUCTION**

24 Cassava (*Manihot esculenta* Crantz) is a tropical crop native to South America that plays  
25 a central role in food security in developing countries due to its high energy content (OLSEN

1 & SCHAAL, 1999). The crop has broad potential for use: its roots are important sources of  
2 starch for both human consumption and industrial applications, while the protein- and vitamin-  
3 rich aerial parts represent valuable resources for human and animal nutrition (FERNANDES et  
4 al., 2020).

5 The distinction between sweet and industrial cassava is primarily based on the  
6 concentration of cyanogenic compounds. For consumption, after simple processing such as  
7 cooking, the roots must contain hydrogen cyanide (HCN) levels below 100 mg kg<sup>-1</sup>. (VIEIRA  
8 et al., 2022). For industrial purposes, this threshold is less restrictive, as the processing of flour,  
9 starch, and ethanol effectively eliminates toxicity.

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

16 Validating cultivars across multiple environments is a critical stage in breeding programs,  
17 as genotype × environment (G×E) interaction can reduce the predictability of agronomic  
18 performance and limit broader recommendations (CEBALLOS et al., 2021). Recent studies  
19 have demonstrated substantial genetic variability for traits such as yield, plant architecture, and  
20 root quality under different cassava production systems (SILVA et al., 2014; PAZ et al., 2020).

21 In this context, developing an ideotype for sweet cassava requires the integration of  
22 technological and sensory attributes. From a technological perspective, desirable traits include  
23 high root yield, rapid emergence, plant architecture suitable for mechanization, ease of root  
24 detachment, efficient water use, easier peeling of the cortex and periderm, and earliness, among  
25 others. From a sensory standpoint, essential characteristics include low HCN content, reduced

1 cooking time (< 30 min), typical organoleptic properties, and soft texture (FUHRMANN et al.,  
2 2020; CEBALLOS et al., 2021; VIEIRA et al., 2022).

3 Despite its importance, robust experimental trials remain scarce in the state of Goiás.  
4 Such studies are essential for establishing regional parameters aimed at increasing productivity  
5 and local income, particularly given that proper crop management and the selection of adapted  
6 genotypes are key factors in reducing yield gaps in sweet cassava production in Brazil  
7 (BEXAIRA et al., 2026).

8 Given this gap, the present study aimed to assess the agronomic performance of sweet  
9 cassava genotypes in two contrasting Cerrado environments in Goiás.

## 10 MATERIALS AND METHODS

11 The experiments were conducted during the 2020/2021 growing season at two  
12 experimental stations with contrasting edaphoclimatic conditions of the Goiana Agency for  
13 Technical Assistance, Rural Extension, and Agricultural Research (EMATER-GO). The first  
14 environment, representing the central region of Goiás, was the Santa Vitória Experimental  
15 Station, located in Araçu (16°16' S, 49°44' W; 716 m altitude), characterized by an average  
16 annual rainfall of 1,357 mm, with mean maximum and minimum temperatures of 29.4°C and  
17 17.0°C, respectively. The second environment, located in the northern region of the state, was  
18 the Lages Experimental Station in Porangatu (13°18' S, 49°07' W; 390 m altitude), with average  
19 rainfall of 1,095 mm and a warmer thermal regime, with mean maximum and minimum  
20 temperatures of 31.7°C and 27.8°C, respectively.

21 The two environments differed markedly in their soil physical and chemical properties.  
22 The soil in Araçu was more fertile than that in Porangatu, with pH (CaCl<sub>2</sub>) values of 5.4 and  
23 4.3, and base saturation of 64% and 46%, respectively. Macronutrient levels were also higher  
24 in Araçu - P (44 vs. 10 mg dm<sup>-3</sup>), K (230 vs. 140 mg dm<sup>-3</sup>), and Ca (4.6 vs. 1.2 cmolc dm<sup>-3</sup>).  
25 Soil texture ranged from 37% clay and 47% sand in Araçu to 42% clay and 36% sand in

1 Porangatu. Organic matter content and potential acidity ( $H^+ + Al$ ) were 2.8% and  $3.5 \text{ cmolc dm}^{-3}$   
2 in Araçuaçu, and 1.3% and  $2.4 \text{ cmolc dm}^{-3}$  in Porangatu, respectively.

3 A randomized complete block design with three replications was adopted. Treatments  
4 consisted of ten sweet cassava genotypes, including five cultivars developed by Embrapa  
5 Cerrados (BRS 396, BRS 397, BRS 398, BRS 399, and BRS 429); three local landraces selected  
6 by EMATER-GO (Branca Pancinha, Cacau, and Branca de Rio Verde); and two widely  
7 cultivated checks in Goiás production systems (IAPAR 19 and IAC 576-70).

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

12 Harvest was carried out approximately 12 months after planting at both locations. The  
13 following traits were evaluated: plant height (PH, m), height of first branching (HFB, cm), stem  
14 diameter (SD, cm), number of roots per plant (NRP), shoot yield (SY,  $\text{t ha}^{-1}$ ), root yield (RY,  $\text{t}$   
15  $\text{ha}^{-1}$ ), harvest index (HI), calculated as the ratio of root mass to total plant mass, cooking time  
16 (CT, min) according to BORGES et al. (2002), starch content (SC, %), determined by the  
17 hydrostatic balance method (GROSSMANN & FREITAS, 1950), and starch yield (StY,  $\text{t ha}^{-1}$ ).

18 Data were subjected to individual and combined analyses of variance using mixed linear  
19 models, with genotypes treated as fixed effects and environments as random effects. Means  
20 were grouped using the Scott-Knott test at the 5% significance level (SCOTT & KNOTT, 1974).  
21 Additionally, to investigate the correlation structure among variables, Principal Component  
22 Analysis (PCA) was performed to identify patterns of association among traits and to  
23 differentiate genotype performance. The analysis was based on the correlation matrix of  
24 standardized data to eliminate scale effects. A biplot of PC1 and PC2 was generated using the  
25 InfoStat statistical software (DI RIENZO et al., 2020).

## 1    **RESULTS AND DISCUSSION**

2            The combined analysis of variance for plant height (PH), height of first branching (HFB),  
3    and stem diameter (SD) revealed significant effects of genotype and environment for all  
4    variables, except for the genotype effect on SD (Table 1). This result indicates phenotypic  
5    variability among the evaluated genotypes (VIEIRA et al., 2018; PAZ et al., 2020). In contrast,  
6    the genotype  $\times$  environment (G $\times$ E) interaction was significant only for HFB, reflecting the  
7    adaptive plasticity of cassava (CEBALLOS et al., 2004) and indicating greater sensitivity of  
8    this trait to environmental variation. This finding differs from that reported by PAZ et al. (2020),  
9    who did not observe a genotype  $\times$  season interaction for HFB. This discrepancy can be  
10   physiologically explained because branching occurs when flowering-induced by photoperiod-  
11   breaks apical dominance (EL-SHARKAWY, 2004). Therefore, environmental variation is  
12   expected to exert a stronger influence on HFB expression than year-to-year variation.

13            The overall mean for PH was 2.59 m, which exceeded the value reported by CEBALLOS  
14   et al. (2004) in Colombia (2.1 m), suggesting good adaptation of the genotypes to the Cerrado  
15   conditions. Mean comparison tests grouped the genotypes into two categories, with the cultivar  
16   BRS 429 placed in the superior group (Table 1). No lodging was observed despite the relatively  
17   tall plant stature in the experimental areas. For HFB, the interaction breakdown revealed  
18   contrasting genotype responses across environments. In Araçá, two groups were formed, with  
19   BRS 429, IAPAR 19, and Branca Pancinha showing superior performance. In Porangatu,  
20   greater discrimination was observed, resulting in three groups, with BRS 429 standing out  
21   again.

22            The selection of genotypes with higher mean values for PH, HFB, and SD is essential for  
23   the recommendation of new commercial cultivars, given the direct influence of these traits on  
24   field operational efficiency. From an agronomic standpoint, plants with this architecture favor  
25   mechanized planting and facilitate crop management practices such as weed control,

1 phytosanitary inspections, and pesticide applications. Moreover, greater vegetative growth  
2 increases the availability of high-quality stem cuttings for propagation and enables the aerial  
3 part to be used as a protein source for animal feed, thereby adding value to the production  
4 system (FERNANDES et al., 2020; VIEIRA et al., 2020). In this context, BRS 429  
5 distinguished itself among the evaluated genotypes by its superior performance in PH, HFB,  
6 and SD.

7 For shoot fresh weight (SY), number of roots per plant (NRP), root yield (RY), and  
8 harvest index (HI), the analysis of variance revealed significant genotype effects for all  
9 variables (Table 2). However, the genotype  $\times$  environment (G $\times$ E) interaction was significant  
10 only for RY. This result was expected and supports the quantitative and polygenic nature of RY,  
11 a trait strongly influenced by soil and climatic conditions, which affect the genotype-phenotype  
12 relationship and yield stability (VIEIRA et al., 2020; CEBALLOS et al., 2021). This finding  
13 reinforces the need for multi-environment trials to ensure accurate selection. Conversely, the  
14 absence of a significant interaction for SY indicates greater consistency of shoot biomass  
15 production across environments. The detected genetic variability for this trait is strategically  
16 important, as it enables the selection of genotypes with high potential for forage production  
17 (FERNANDES et al., 2020). Stability in green biomass supply is essential to support the use of  
18 the aerial part as a protein source in animal feeding systems, consolidating the dual-purpose  
19 potential of selected cultivars.

20 Fresh root yield (RY) ranged from 25.95 to 39.90 t ha<sup>-1</sup> in Araçá and from 25.98 to 47.96  
21 t ha<sup>-1</sup> in Porangatu (Table 2). In Araçá, BRS 397, BRS 429, BRS 396, Branca de Rio Verde,  
22 BRS 396, BRS 399, BRS 398, and IAC 576-70 were among the top-performing genotypes,  
23 whereas in Porangatu, BRS 397, BRS 398, BRS 396, BRS 429, Branca Rio Verde, IAC 576-  
24 70, BRS 399, and Branca Pancinha performed best, with no significant differences among  
25 genotypes within the superior group in either environment. The yields obtained in this study

1 markedly exceeded the state average, highlighting the high productive potential of cassava  
2 when grown under adequate management and genetic selection. This result is consistent with  
3 recent studies demonstrating that optimization of agronomic factors can substantially increase  
4 sweet cassava yields in tropical environments (BEXAIRA et al., 2026).

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

10       The number of roots per plant (NRP) ranged from 8.25 to 12.18 among genotypes, with  
11 IAC 576-70, BRS 397, BRS 399, and BRS 396 showing superior performance (Table 2). The  
12 harvest index (HI) ranged from 0.41 to 0.59 (Table 2). HI values above 0.50 indicate optimal  
13 physiological efficiency in the translocation of photoassimilates to the roots; in this study, 80%  
14 of the genotypes exceeded this threshold, with Cacau and BRS 399 showing the lowest values.

15       Regarding technological quality, a significant genotype effect was observed for starch  
16 content (SC) and starch yield (StY), indicating exploitable genetic variability (Table 3). The  
17 overall mean SC was 29.26%, with the local genotypes Branca Pancinha, Branca de Rio Verde,  
18 and Cacau, along with IAPAR 19, BRS 429, and IAC 576-70, presenting the highest values.  
19 Except for IAC 576-70, all these genotypes exhibited SC values above 30%. Although starch  
20 content is traditionally considered a secondary trait in sweet cassava breeding, it is directly  
21 associated with root texture and final consumer acceptance (CEBALLOS et al., 2021).

22       The average cooking time (CT) was 25.85 minutes (Table 3), with all genotypes  
23 presenting values below 30 minutes, which is the maximum acceptable threshold for  
24 commercialization of sweet cassava (BORGES et al., 2002). The absence of significant  
25 differences among genotypes and in the G×E interaction, in contrast with the significant effect

1 of environment, indicates genetic uniformity among the evaluated genotypes for this trait. In  
2 this context, variation in cooking time was predominantly driven by environmental conditions,  
3 a pattern that contrasts with the genotypic instability often reported in the literature (BORGES  
4 et al., 2002; VIEIRA et al., 2018).

5 In summary, the cultivar BRS 429 stood out across the contrasting environments of the  
6 Cerrado region of Goiás. Because it combined superior performance in most agronomic traits  
7 including favorable plant architecture, high yield, and desirable root quality, this genotype  
8 highlights the effectiveness of participatory breeding approaches in identifying superior  
9 genotypes adapted to the demands of the production chain (VIEIRA et al., 2022).

#### 10 *Principal Component Analysis (PCA)*

11 The graphical dispersion based on the first two principal components (PC1 and PC2)  
12 revealed distinct patterns of trait association and genotype grouping, jointly explaining 64.20%  
13 of the cumulative variance (Figure 1). The cophenetic correlation coefficient was 85%,  
14 indicating high-quality clustering. This value is considered robust for cassava genetic diversity  
15 studies, given the quantitative nature of the evaluated traits (NDUWUMUREMYI et al., 2017).

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

20 Vector analysis, based on the geometric interpretation of the biplot proposed by DI  
21 RIENZO et al., (2020), identified agronomically relevant positive correlations, such as those  
22 between RY and starch yield (StY) and between plant height (PH) and SY (Figure 1).  
23 Conversely, negative correlations were observed between SC and StY, and between SY and  
24 HFB, reinforcing the complexity of simultaneous selection in cassava breeding.

25 In terms of genotype distribution, the group comprising BRS 429 and BRS 396 stood out

1 due to their strong association with high root yield (RY) and starch yield (StY), whereas BRS  
2 397 was characterized by a high number of roots per plant (NRP). The genotypes BRS 399 and  
3 Cacau were associated with greater vegetative vigor, as indicated by higher SY and PH values.  
4 In contrast, BRS 398 was positioned in the direction of higher cooking time (CT) and harvest  
5 index (HI) values, suggesting possible limitations for the fresh market (Figure 1).

6 The cultivar Branca Pancinha was associated with quality-related traits, particularly  
7 starch content (SC). Finally, the cultivars BRS 429, IAC 576-70, and IAPAR 19 were located  
8 near the center of the biplot (Figure 1), indicating lower phenotypic sensitivity and greater  
9 agronomic stability across contrasting environments. This positioning reflects a balanced  
10 expression of the evaluated traits and supports their productive stability as observed in the mean  
11 performance analysis.

## 12 CONCLUSION

13 The agronomic evaluation of sweet cassava genotypes under contrasting environments in  
14 the Cerrado region of Goiás revealed significant variability in yield. The cultivar BRS 429  
15 consistently excelled in most agronomic traits, exhibiting lower sensitivity to genotype ×  
16 environment (G×E) interaction, indicating greater phenotypic stability.

17 Based on its superior performance and adaptability, BRS 429 is recommended the cultivar  
18 best suited for cultivation under the soil and climatic conditions evaluated, with strong potential  
19 to increase productivity and improve production-system efficiency in the region.

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#### 15 **CONFLICT OF INTEREST STATEMENT**

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

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#### 21 **AUTHOR CONTRIBUTIONS**

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

1 **Table 1** - Summary of the combined analysis of variance for plant height (PH), height of first  
 2 branching (HFB), and stem diameter (SD) in 10 cassava genotypes evaluated in two contrasting  
 3 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 <sup>ns</sup>
GxL	9	0.10 <sup>ns</sup>	0.13**	0.09 <sup>ns</sup>
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	2.93
Cacau		2.81a	0.81b	2.97
BRS 399		2.78a	0.79b	3.02
IAPAR 19		2.71a	1.40a	2.96
BRS 397		2.64a	0.80b	2.95
BRS 396		2.59a	0.90b	3.08
Branca Rio Verde		2.59a	1.06b	3.23
IAC 576-70		2.57a	0.93b	3.07
Branca Pancinha		2.16b	1.40a	2.87
BRS 398		2.15b	1.11b	3.14

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

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

SV	d.f.	Mean squares				
		SY (t ha <sup>-1</sup> )	NRP	RY (t ha <sup>-1</sup> )	HI	
Local (L)	1	38.66 <sup>ns</sup>	0.84 <sup>ns</sup>	307.00*	0.09*	
Genotypes (G)	9	261.74**	10.32*	134.16**	0.02**	
G*L	9	43.94 <sup>ns</sup>	4.48 <sup>ns</sup>	129.87**	0.003 <sup>ns</sup>	
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		Araçá		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

4 ns, \*\* and \*: not significant, significant at  $p \leq 0.01$ , and significant at  $p \leq 0.05$ , respectively, according to the F test.

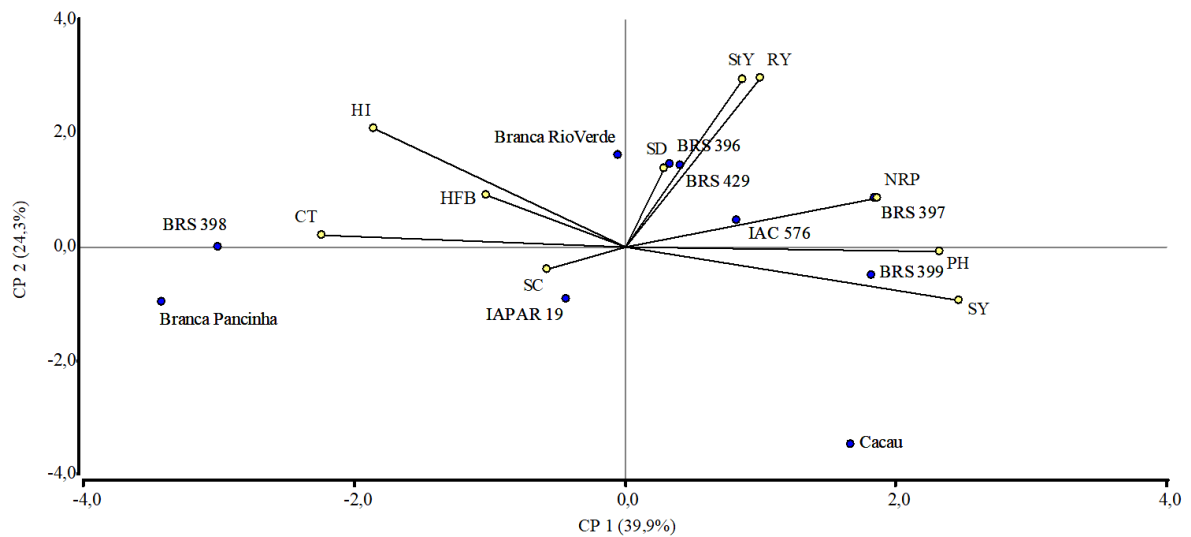
5 SV: Source of Variation; d.f.: degrees of freedom; CV: Coefficient of Variation; Means followed by the same letter

6 within the same column belong to the same group, according to the Scott-Knott test, at  $p \leq 0.05$ .

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

SV	d.f.	Mean squares			
		SC (%)	StY (t ha <sup>-1</sup> )	CT (min)	
Local (L)	1	45.23*	16.95 <sup>ns</sup>	2294.02**	
Genotype (G)	9	16.94**	12.02*	11.76 <sup>ns</sup>	
G*L	9	4.23 <sup>ns</sup>	12.74*	10.94 <sup>ns</sup>	
Residual	35	4.70	4.70	7.10	
Mean		29.26	19.67	25.85	
CV (%)		7.41	10.19	10.31	
Genotype			Araçá	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

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



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

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