Doi: https://doi.org/10.17584/rcch.2022v16i2.14090

Genetic contributions to productivity and nutritional aspects in cassava crops

Aportes genéticos a la productividad y aspectos nutricionales del cultivo de yuca

ADRIANO UDICH BESTER[1, 4]
IVAN RICARDO CARVALHO[2]
MURILO VIEIRA LORO[3]
ADRIANO HIRSCH RAMOS[1]
INAÊ CAROLINA SFALCIN[2]
JOSÉ ANTONIO GONZALEZ DA SILVA[2]
FELIPE DA ROSA FOGUESATTO[2]
MARCOS VINÍCIUS UHDE FOGUESATTO[2]

Cassava root - cultivar FEPAGRO - RS 13 Vassourinha.

Photo: A.U. Bester

ABSTRACT

This study aimed to highlight the behavior of cassava cultivars when subjected to different densities and biostimulants at planting and to select superior cultivars based on nutritional and productive attributes using the multivariate approach. The experiment design used randomized blocks in a three-factor scheme, with three cassava cultivars (FEPAGRO-RS 13 Vassourinha, BRS CS01, Iapar - 19 Pioneira) × two planting densities (10 and 20 buds per linear meter) × two biostimulator forms (with and without) in three replications, totaling 36 experiment units. Cultivar BRS CS01 had the highest yield and concentration of mineral material, genotype FEPAGRO - RS 13 Vassourinha had the highest lipid content, and Iapar 19 - Pioneira had the highest protein concentrations. The starch content was tested with a comparison of means and MGIDI index. Cultivar FEPAGRO - RS 13 Vassourinha had the highest content and, according to the index, was the ideal cultivar based on multi-characteristics. Density 10 with the biostimulator was favorable for productivity and lipids, whereas density 10 without the biostimulator was favorable for starch, lipids, proteins and productivity. Density 20 with the biostimulator was favorable for lipids.

Additional keywords: *Manihot esculenta* Crantz; heritability; MGIDI index; density; biostimulator.

[1] Universidade Federal de Pelotas (UFPel), Pelotas (Brazil). ORCID Bester, A.U.: 0000-0002-7728-7914; ORCID Ramos, A.H.: 0000-0001-9146-3024
[2] Universidade Regional do Noroeste do Rio Grande do Sul (UNIJUI), Ijui (Brazil). ORCID Carvalho, I.R.: 0000-0001-7947-4900; ORCID Sfalcin, I.C.: 0000-0002-7800-5392; Silva, J.A.G.: 0000-0002-9335-2421; Foguesatto, F.R.: 0000-0002-5798-0973; ORCID Foguesatto, M.V.U.: 0000-0002-3441-6798
[3] Universidade Federal de Santa Maria (UFSM), Santa Maria (Brazil). ORCID Loro, M.V.: 0000-0003-0241-4226
[4] Corresponding author. adriano.udich.bester@gmail.com

RESUMEN

El objetivo de este trabajo es resaltar el comportamiento de cultivares de yuca sometidos a diferentes densidades y bioestimulantes al momento de la siembra, y seleccionar cultivares superiores a través de atributos nutricionales y productivos basado en el enfoque multivariado. Se utilizó un diseño experimental de bloques al azar de tres factores y tres repeticiones: tres cultivares de yuca (FEPAGRO-RS 13 Vassourinha, BRS CS01, Iapar - 19 Pioneira), dos densidades de plantación (10 y 20 yemas por metro lineal) y bioestimulate (con y sin), en total 36 unidades experimentales. El cultivar BRS CS01 presentó el mayor rendimiento y concentración de material mineral; el genotipo FEPAGRO - RS 13 Vassourinha presentó el mayor contenido de lípidos y 'Iapar 19 - Pioneira' presentó las mayores concentraciones de proteína. El contenido de almidón fue evaluado por la prueba de comparación de medias e índice MGIDI. El cultivar FEPAGRO - RS 13 Vassourinha mostró superioridad, además de ser considerado por el índice ideal por el multi-variado. La densidad 10 y bioestimulador se caracterizó como favorable para la productividad y lípidos, mientras que la densidad 10 y sin bioestimulador favorable para almidón, lípidos, proteína y productividad. La densidad 20 con bioestimulador fue favorable para lípidos.

Palabras clave adicionales: *Manihot esculenta* Crantz; heredabilidad; índice MGIDI; densidad; bioestimulador.

Received: 10/03/2022 Accepted: 16/05/2022 Published: 29/06/2022

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is of great importance worldwide. It is a staple food for more than one billion people in more than 100 countries around the world (Albuquerque *et al*., 2012). Its cultivation is widely developed in tropical Africa, Asia and Latin America, mainly in underdeveloped and developing countries. In regions such as Northeast Brazil, countries such as Ghana and Nigeria and some parts of Indonesia, cassava provides about 70% of the daily calorie consumption of the population (Nassar *et al*., 2006).

Its vast cultivation is mainly due to its genetic characteristics, which include rusticity, tolerance to drought and acidic soils, high adaptive capacity and low production cost. It has become one of the main sources of carbohydrates in the world (Bester *et al*., 2021). According to the latest survey by the Food and Agriculture Organization of the United Nations, global production of cassava roots was 291 million tons in an area of approximately 26.3 million hectares, with an increase of 55 and 66%, respectively, since 2000 (FAO, 2019).

Through genetic improvement, cassava crop has made great progress, such as an expressive increase in productive potential and nutritional root quality through new cultivars. Bester *et al*. (2021), in a study on a 30-year historical series, reported an increase in cassava productivity in Brazil. Species diversity is a resource that can be used as a source of genetic variation for incorporating genes into new varieties (Pádua, 2018). Many genes of great importance have not yet been found in this vast germplasm bank, whether they are linked to increased productivity, starch content and quality or tolerance to drought, pests and diseases, representing an important line of research (Oliveira *et al*., 2016).

Selection strategies were created, including the Restricted Maximum Likelihood (REML) and Best Linear Unbiased Prediction (BLUP) methods. These methods are used to estimate parameters and predict genetic values, without the environmental effects on phenotype, in which only the studied genetic characteristics remain. They are important methods in guiding breeding programs (Pimentel *et al*., 2014). Thus, the mixed model makes it possible to obtain variance components and genetic parameters through the restricted maximum likelihood (Baretta *et al*., 2016) and can help in the selection and prediction of genotypes through the best non-targeted linear predictor (BLUP), indicating the genetic value and the new predicted mean (Carvalho *et al.*, 2016).

For the importance of nutritional quality and the need to demonstrate the effects of the cultivation environment on these characteristics, another method of analysis called Annicchiarico can be used, which demonstrates the stability of genotypes in a given environment. The results reflected a confidence index for each genotype that showed which genotypes were superior and classified environments as favorable or unfavorable for the relevant characteristic (Cruz *et al*., 2014).

This study aimed to highlight the behavior of cassava cultivars when subjected to different densities and biostimulants at planting and to select superior cultivars based on nutritional and productive attributes using the multivariate approach.

MATERIALS AND METHODS

This study was carried out in the municipality of Augusto Pestana/RS (Brazil). The soil was classified as Typical Distroferric Red Latosol (Santos *et al*., 2018). According to the Köppen climate characterization, the climate of the region was Cfa type.

The experiment design used randomized blocks with three replications in a 3×2×2 triple factorial scheme (three cultivars, two planting densities and with or without plant regulator). The treatments consisted of three cassava cultivars: FEPAGRO-RS 13 Vassourinha, BRS CS01, and Iapar - 19 Pioneira in four environments, namely: density 10 (10 buds per linear meter) with biostimulator, density 10 without biostimulator, density 20 with biostimulator (20 buds per linear meter) and density 20 without biostimulator. The experiment consisted of 36 plots of 6 linear meters, according to the treatments, with a spacing of one meter between lines.

The soil was prepared with subsoiling and opening of the planting lines. At the same time, the fertilization and soil correction were carried out according to the soil analysis for the area following the technical recommendations for cassava crops (CQFSRS, 2004). The crop was planted at the end of September 2019 by manually transplanting stems that were deposited in a horizontal position at the bottom of the furrows.

The cassava harvest was carried out 9 months after the transplanting the cuttings. The start was done manually where the roots were collected, cleaned and sent to the UNIJUÍ plant production laboratory, where productivity measurements were taken (t ha^{-1}), and drying was done in an oven (105±5°C). After drying, the samples were ground in a willey mill and sent to the Food Microbiology Laboratory of the Federal University of Pelotas, where the following variables were measured:

Mineral material (MM, %): the Mineral material content was obtained after incineration of the sample in a muffle furnace at a temperature of 550°C, following the method described by the Association of Official Analytical Chemises (AOAC, 2005); lipid content (oil, %): the lipid content was determined with solvent extraction using a Soxhlet extractor with ether as the reagent, following the method described by Soxhlet (1879); protein content (P, %): the protein determination was based on nitrogen with the Kjeldah digestion process. The organic matter was broken down, and the existing nitrogen was finally transformed into ammonia, introducing an empirical factor of 6.25 to transform the number of grams of nitrogen into the number of grams of protein, according to the AOAC procedures; starch content (S, %): The tuber samples were immersed in water overnight, then ground in a blender, and the starch was filtered through a fine mesh (opening size: 350 μm), immersed in water to separate the husks from the suspension, and allowed to settle overnight. After decanting, the sedimented starch was rinsed several times with distilled water, pressed onto a clean muslin cloth and dried at 45°C in a hot air oven (D-37520, Thermo Fischer Scientific, Pretoria, South Africa) for 12 h. The dry starch was stored at 4°C until analysis, a maximum period of one week; this methodology was adapted from the article by Oyeyinka *et al*. (2019).

The data were analyzed using the R software and submitted to analysis of variance (ANOVA) to detect the presence or absence of interaction between the factors. Then, based on this information, the means comparison test was performed for the variables with the Tukey method ($P<0.05$). Afterwards, the method of Annicchiarico (1992) was used, which was applied to the starch, protein, lipid, mineral material and productivity, following the methodology proposed by Cruz *et al*. (2014). To estimate the variance components and genetic parameters (REML) for half-sibling progenies and meet the assumptions of the experiment, the genotypic variance (σ^2G), residual variance (σ^2E), individual phenotypic variance (σ^2F), broad-sense heritability for total genotypic effects ($\hat{H}^2g$), mean genotype heritability ($\hat{H}^2mg$), accuracy for genotype selection ($\check{r}\breve{g}\breve{g}$), genotypic coefficient of variation (CVg %), residual coefficient of variation (CVe %) and rate of the coefficient of variation (CVr) were estimated according to the methodology proposed by Ramalho *et al*. (2012). Subsequently, the Deviance analysis (LRT) was performed at $P<0.05$ probability with the chi-square test (X^2) to identify the significance of the characteristic. BLUP (Best Linear Unbiased Predictor) estimates were used to obtain the components of the means. Finally, the multi-trait genotype-ideotype distance index (MGIDI) was used to identify genotypes that combined high productive performance with high nutritional quality.

RESULTS AND DISCUSSION

In the analysis of variance (Tab. 1), the cultivar × density interaction exhibited a significant effect only for starch, whereas the protein variable exhibited an effect with the cultivar × density × biostimulator interaction, and the density × biostimulator exhibited a significant effect on protein. The source of the cultivar variation showed a significant effect on the variables starch, protein and lipid. This result is similar to that found by Teixeira (2017), who, when evaluating nineteen varieties of table cassava, observed a difference between all characteristics, including starch, protein and lipids, with the exception of mineral material. On the other hand, in terms of density, only a significant effect was observed for starch, and the source of the biostimulator variation had an effect on the lipid content.

The descriptive analysis (Fig. 1) showed that cultivar BRS CS01 had the highest productivity, and cultivar Iapar 19 - Pioneira exhibited the greatest variation between treatments for lipid content in the roots, cultivar FEPAGRO - RS 13 Vassourinha stood out with little variation between treatments, with Iapar 19 - Pioneira showing the lowest content, followed by a large variation between treatments. For starch content, there was no significant difference between cultivars and treatments. In terms of protein content, cultivar Iapar 19 - Pioneira stood out with the highest averages, and FEPAGRO - RS 13 Vassourinha presented the lowest content. For the mineral material content, cultivar BRS CS01 had the highest productivity; however, it did not differ from cultivar Iapar 19 – Pioneira. FEPAGRO - RS 13 Vassourinha had the lowest average.

For starch content (Tab. 2), density 10 had no statistical difference between the cultivars; however, at density 20, cultivar FEPAGRO - RS 13 Vassourinha showed the highest starch content, followed by BRS CS01 and Iapar 19 - Pioneira. When the spacing between plants was reduced, there was an influence on starch content. The shape of the root system may have caused this modification since FEPAGRO - RS 13 Vassourinha has shorter roots than the other two cultivars, resulting in less competition between plants. For biostimulator use, there was no difference between the cultivars; however, genotype FEPAGRO - RS 13 Vassourinhas had an average of 9.96 without it. For the interaction, density 10 had no effect from the biostimulator. Density 20 with the biostimulator presented the highest average, 7.26.

Table 1. Summary of joint analysis of variance for nutritional quality (starch, protein, mineral material and lipid) and yield of three cassava cultivars produced at different densities with or without the use of biostimulant.

Variation factor	DF	Starch (%)	Protein (%)	Mineral material (%)	Productivity (t ha^{-1})	Lipid (%)
Block	2	3.1	0.1	$1.00 \cdot 10^{-05}$	2862.8	$9.00 \cdot 10^{-05}$
Cultivar	2	14.5*	0.8*	$1.00 \cdot 10^{-05}$	9755.2	0.20*
Density	1	11.6*	0.007	0	5536.4	0.04
Biostimulator	1	2.4	0.2	0	130.2	0.08*
Cultivar × Density	2	10.5*	0.4	0	2185.8	0.06
Cultivar × Bioestimulator	2	7.6	3.4	$1.00 \cdot 10^{-05}$	7695.4	0.01
Density × Bioestimulator	1	7.9	0.2*	0	1159.4	0.10
Cultivar × Density × Bioestimulador	2	2.8	3.7*	0	643.9	0.02
Residue	22	1.4	3.7	0	3212.7	0.01
Total	33					

* Statistically significant at $P<0.05$.

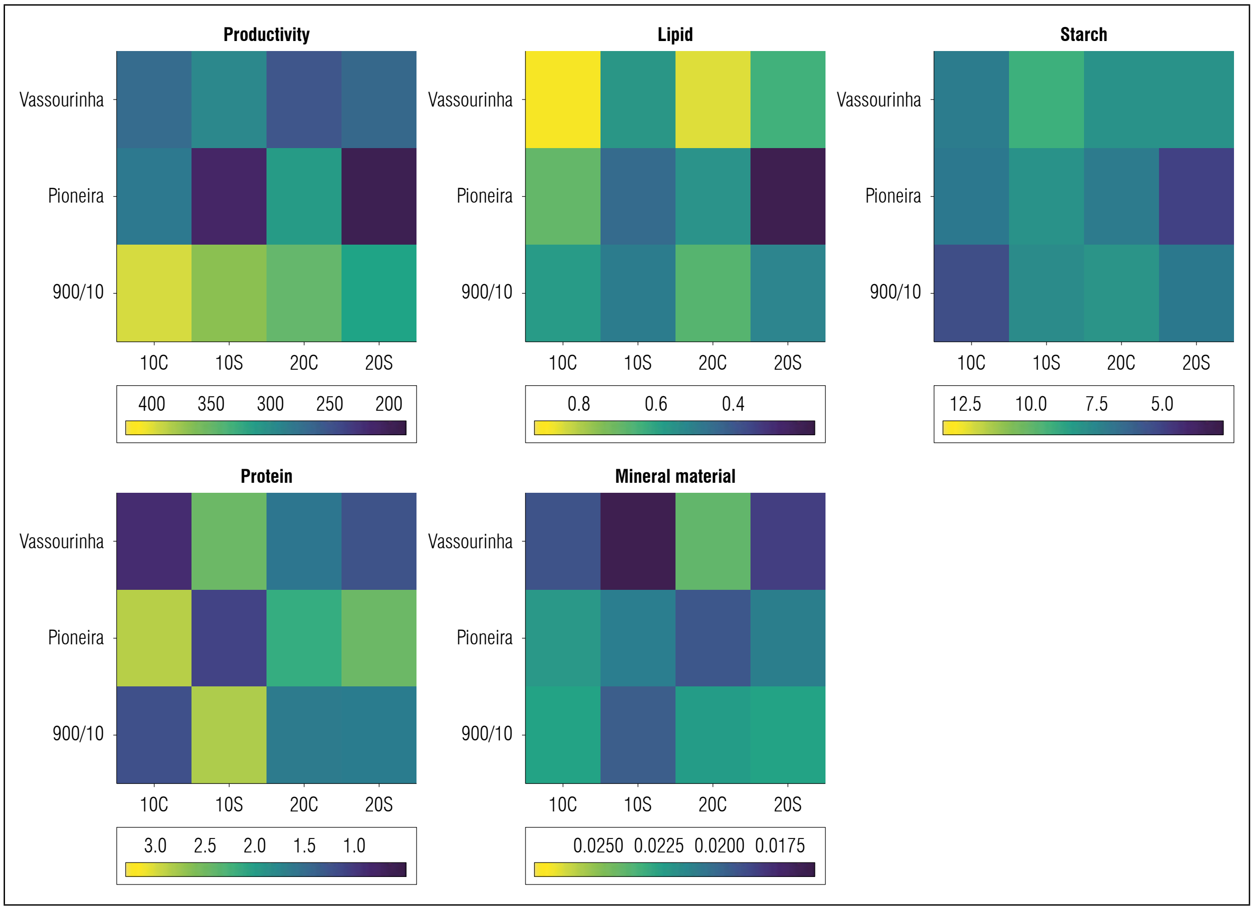

Figure 1. Descriptive analysis containing the means of the variables studied (productivity, lipid, starch, protein and mineral material) in *Manihot esculenta* Crantz.

Table 2. Breakdown of simple effects for cultivar × planting densities, cultivar × biostimulator and density × biostimulator for starch percentage (%) three cassava cultivars produced in different planting densities, with or without the use of biostimulant.

Density	FEPAGRO-RS 13 Vassourinha	BRS CS01	Iapar 19 - Pioneira
10	8.78 aA	7.39 aA	8.38 aA
20	8.92 aA	7.12 bA	5.10 bB
Bioestimulator			
With	7.34 aB	7.13 aA	7.20 aA
Without	9.96 aA	7.39 bA	6.28 bB

Density	Bioestimulator	
	With	Without
10	6.46 aB	6.92 aA
20	7.26 aA	6.84 bB

Means followed by the same lowercase letter in the row and uppercase in the column do not differ from each other by Tukey test ($P<0.05$).

When considering the protein content for density 10 with the biostimulator (Tab. 3), cultivar Iapar 19 - Pioneira had the highest average, 3.02. On the other hand, without the biostimulator, cultivars FEPAGRO - RS 13 Vassourinha and BRS CS01 presented the highee means, 2.84 and 2.6, respectively. At density 20, only cultivar FEPAGRO - RS 13 Vassourinha differed in the treatment with the biostimulator, presenting the lowest average. However, the others did not differ statistically. Comparing the different densities, there was a difference for FEPAGRO - RS 13 Vassourinha with the biostimulator, where the treatment with 20 buds per linear meter was superior. The same was repeated in the BRS CS01 cultivar. Cultivar Iapar 19 – Pioneira only differed in the treatment without biostimulator use, where density 20 presented the best average.

For the lipid content (Tab. 4), cultivar FEPAGRO - RS 13 Vassourinha expressed the highest average at density 10 and at density of 20 buds per linear meter, the cultivars that stood out were FEPAGRO - RS 13 Vassourinha and BRS CS01. Cultivar Iapar 19 – Pioneira differed between the two densities, where density 10 presented the highest average. For the interaction between density and biostimulator use, the worst average was obtained in the treatment without biostimulator at density 20.

The production environments that were efficient were favorable for the variable's percentage of mineral material, starch, protein, lipid and productivity. The phenotypic stability analysis was used using the Annicchiarico method (Tab. 5) to identify which cassava genotype and cultivation environments showed greater efficiency. Density 20 with the biostimulant was favorable to the characteristics mineral and lipid material, along with density 10 with and without biostimulator for the latter. For starch and protein, only density 10 without the biostimulator was favorable. In terms of productivity, the favorable environment was density 10 with and without biostimulator.

Therefore, in terms of favorable and unfavorable environments (Tab. 6) for percentage of mineral material, starch, lipid, protein and productivity, the best cultivar was BRS CS01, and the lowest performance was in FEPAGRO-RS 13 Vassourinha. The same pattern was repeated for mineral material and productivity for unfavorable environments, different from the

Table 3. Breakdown of simple effects for cultivar × planting density × biostimulator for the character percentage of protein (%) in three cassava cultivars produced at different planting densities with or without the use of biostimulant.

Density	FEPAGRO-RS 13 Vassourinha		BRS CS01		Iapar 19 - Pioneira	
	With	Without	With	Without	With	Without
10	0.92 bAβ	2.84 aAα	1.53 bBβ	2.60 aAα	3.02 aAα	0.85 bBβ
20	1.29 bAα	1.54 aBα	2.36 aAα	2.02 aAα	2.11 aBα	2.24 aAα

Averages followed by the same lowercase letter compares cultivars for each density and hormone, uppercase compares hormones within the same cultivar and density, and Greek letter compares density within hormone, do not differ from each other by Tukey test ($P<0.05$).

Table 4. Breakdown of the simple effects of the interaction cultivar × planting density and planting density × biostimulant for percentage of lipid in three cassava cultivars produced at different planting densities with or without the use of biostimulant.

Density	FEPAGRO-RS 13 Vassourinha	BRS CS01	Iapar 19 – Pioneira
10	0.7 aA	0.58 bA	0.56 aA
20	0.64 aA	0.66 aA	0.37 bB

Density	Bioestimulator	
	With	Without
10	0.62 aA	0.63 aA
20	0.66 aA	0.46 bB

Means followed by the same lowercase letter in the row and uppercase in the column do not differ from each other by Tukey test ($P<0.05$).

Table 5. Classification of treatments into favorable and unfavorable to increase the desirable traits, which are percentage of mineral material, starch, protein, lipid and productivity expressed in tons. Through the explicit confidence indexes by the Annicchiarico method, referring to three cassava genotypes, cultivated in four environments.

Mineral material (%)			
Cultivation environments	Mean	Environmental index	Classification
Density 10* with biostimulant	0.0215	-0.000397	U
Density 10 without biostimulant	0.0217	-0.000208	U
Density 20 with biostimulant	0.0227	0.000817	F
Density 20 without biostimulant	0.0217	-0.000212	U
Starch (%)			
Density 10 with biostimulant	7.46	-0.161	U
Density 10 without biostimulant	8.92	1.30	F
Density 20 with biostimulant	7.26	-0.361	U
Density 20 without biostimulant	6.84	-0.776	U
Protein (%)			
Density 10 with biostimulant	1.82	-0.122	U
Density 10 without biostimulant	2.10	0.152	F
Density 20 with biostimulant	1.92	-0.0190	U
Density 20 without biostimulant	1.93	-0.0107	U
Lipid (%)			
Density 10 with biostimulant	0.622	0.0275	F
Density 10 without biostimulant	0.635	0.0399	F
Density 20 with biostimulant	0.663	0.0686	F
Density 20 without biostimulant	0.459	-0.136	U
Productivity (t ha^{-1})			
Density 10 with biostimulant	0.622	4.82	F
Density 10 without biostimulant	0.635	20.0	F
Density 20 with biostimulant	0.663	-8.63	U
Density 20 without biostimulant	0.459	-16.2	U

* 10 cassava buds per linear meter and 20 yolks per linear meter. Favorable (F), Unfavorable (U).

results found for starch and lipid content, where the best was FEPAGRO-RS 13 Vassourinha, and Iapar -19 Pioneer was inferior. For protein, in unfavorable environments, the genotype with the best performance was Iapar 19 Pioneira. FEPAGRO-RS 13 Vassourinha showed lower results.

The genotype selected by the multi-trait genotype-ideotype distance index was FEPAGRO - RS 13 Vassourinha (Fig. 2), which was close to the cut-off point, or red line, which indicated the number of genotypes selected according to the selection pressure, which suggests that this genotype may present ideal characteristics for the study. Table 7 shows that the selection index for the five main components were retained; however, the analyzed data can be 100% explained by two factors when considering the first five main components and cultivar FEPAGRO - RS 13 Vassourinha, which was selected by the MGI-DI index. The first factor explained the content of protein, mineral material, lipids and starch, and the second factor explained productivity.

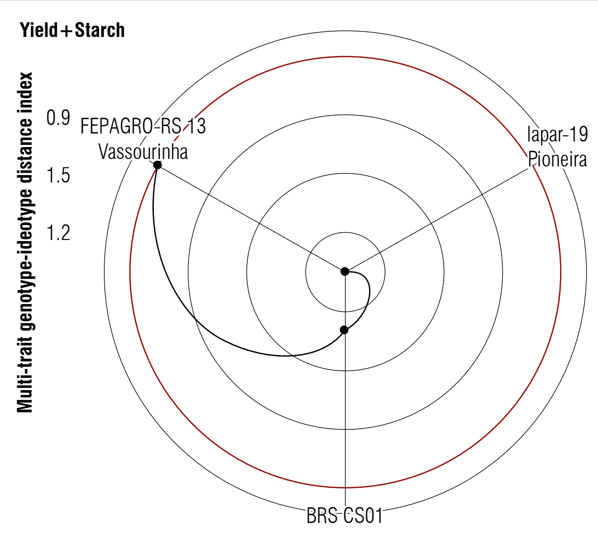

Figure 2. Classification of genotypes of *Manihot esculenta* Crantz in relation to starch content and productivity using the multi-trait genotype-ideotype distance index (MGIDI).

Cultivar FEPAGRO - RS 13 Vassourinha showed an increase in starch content and productivity, which allows it to be evaluated in table 7 in relation to the other cultivars. The heritability factor showed that the lipid variable exhibited the highest genetic heritability, while protein was the lowest. The MGIDI provided desired (positive) gains for lipid and starch characteristics, and the other variables were all negative.

Variance components and genetic parameters (REML) were estimated for three cassava genotypes cultivated in four environments in Rio Grande do Sul (Tab. 8). The phenotypic magnitude of the characteristics was related to effects attributed to the environment, which was part of the genetic variation. Thus, by establishing a joint relationship between individual phenotypic variance (σ^2F) and genotypic variance (σ^2G), it was possible to show that productivity, lipid, starch, protein and mineral material content were determined at 11.7, 49.3, 25.6, 0.00877 and 13.1% by genetic effects, respectively.

Individual phenotypic variance (σ^2F) contributed to the yield and starch characteristics, where σ^2F takes into account the genotype × environment interaction. Removing σ^2G influenced the environment for the characteristic. Broad-sense heritability is related to the percentage of genetic variance existing within the phenotypic variance (Ramalho *et al*., 2012).

Several recent studies have focused on heritability estimates for maize (Ferrari *et al*., 2022), wheat (Carvalho *et al*., 2019), rice (Facchinello *et al*., 2021), white oat (Rosa *et al*., 2021) and soybean (Barbosa *et al*., 2021), contributing to the genetic gain of these crops.

In this context, broad-sense heritability for the total genotypic effects without interference of genotypes × environments interaction ($\hat{H}^2$ g) showed el formato dehigher magnitudes for lipids (0.49) and starch (0.26). Mineral material (0,13), productivity (0,12) and protein (8,77e^{-05}) had the lowest $\hat{H}^2$g. The broad-sense heritability of the genotype mean ($\hat{H}^2$ mg) was high for lipids (0.92) and starch (0.80). High accuracy values demonstrated high experiment precision, with efficiency in the methods of selection and genetic increment of the characteristics (Costa *et al*., 2000). High accuracies (řgğ >0.75) were obtained for all characteristics, except for protein, which showed low accuracy (0.03).

The genotypic variation coefficient (CVg) expressed greater magnitudes for lipids (19.1%), starch (13%) and productivity (8.04%), indicating a greater genetic variability of genotypes for these traits. The residual coefficient of variation (CVe) was higher for protein (46.3%) because this characteristic was influenced by the interaction between genotypes x environments.

In general, the optimal procedure for verifying genetic values is the best unbiased linear predictor (BLUP) as it allows understanding and selection of promising genotypes with information that represents the true genetic value and minimizes the interference of estimates by environmental effects (Borges *et al*., 2010).

Figure 3 shows that cultivar BRS CS01 had higher genetic value for productivity. For lipids and starch, cultivar FEPAGRO - RS 13 Vassourinha showed the highest genetic values. For protein content of the roots, there was no genetic difference between the cultivars. On the other hand, for mineral material, cultivars Iapar 19 – Pioneira and BRS CS01 showed the highest averages.

The methods used by breeding to select certain genetic characteristics show the ideotype with a designated function, either industrial or for both human and animal food. The better methods include descriptive analysis, *Annicchiarico*, MGIDI index, unbiased linear predictor, REML, and BLUP, which, through desired characteristics productivity and starch content, indicate the best genotype.

Table 8. Estimates of variance components and genetic parameters (REML) for the three cassava genotypes, cultivated in four environments. Taking into account the five characters of interest (productivity (t ha^{-1}), lipid (%), starch (%), protein (%), mineral material (%)).

Components of variance REML[1]	Characters				
	Productivity (t ha^{-1})	Lipid (%)	Starch (%)	Protein (%)	Mineral material (%)
σ^2_G	500	0.01	0.973	$7.08 \cdot 10^{-05}$	0.000000572
σ^2_F	4,258	0.03	3.8	0.80	0.00000438
$\hat{H}^2_g$	0.12	0.49	0.26	$8.77 \cdot 10^{-05}$	0.13
$\hat{H}^2_{mg}$	0.62	0.92	0.80	0.00105	0.64
řgğ	0.78	0.96	0.90	0.03	0.80
CVg (%)	8.04	19.1	13.00	0.43	3.46
CVe (%)	22.1	19.3	22.1	46.3	8.92
CVr	0.36	0.99	0.59	0.00936	0.39

[1]σ^2_G: genotypic variance; σ^2_E: residual variance; σ^2_F: individual phenotypic variance; $\hat{H}^2_g$: broad-sense heritability for total genotypic effects; $\hat{H}^2_{mg}$: heritability of the genotype mean; řgğ: accuracy for genotype selection; CVg (%): genotypic coefficient of variation; CVe (%): residual coefficient of variation; CVr: rate of the coefficient of variation.

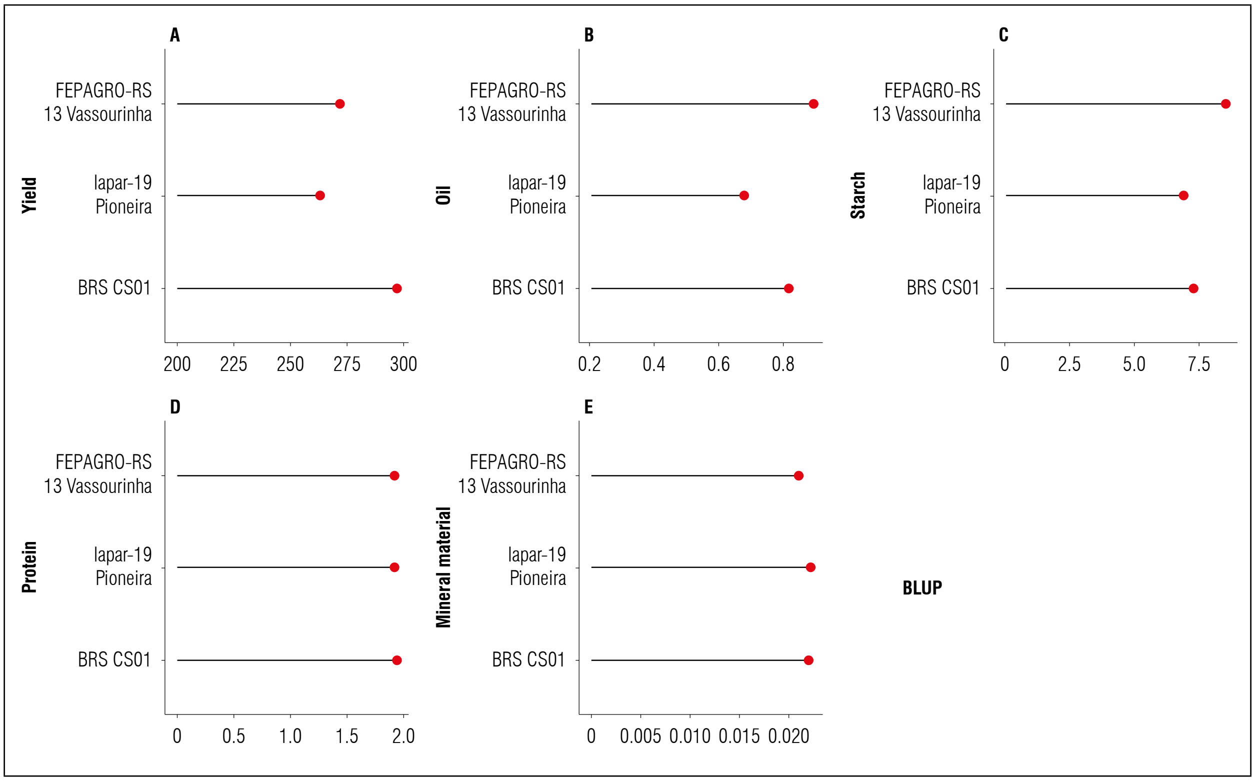

Figure 3. Genetic performance of cassava cultivars for the traits of interest: productivity expressed in t ha^{-1} (A), percentage of oil (B), percentage of starch (C), percentage of protein (D) and percentage of mineral material (D), through the unbiased linear predictor (Best Linear Unbiased Prediction – BLUP). Produced under four different cultivation conditions.

CONCLUSION

Cultivar BRS CS01 showed the highest yield and concentration of mineral material, genotype FEPAGRO – RS 13 Vassourinha had the highest lipid content, and Iapar 19 - Pioneira showed the highest protein concentrations.

The test of comparison of means and MGIDI index showed that cultivar FEPAGRO - RS 13 Vassourinha had the most starch and was the ideal cultivar based on multi-characteristics.

Density 10 with the biostimulator was favorable for productivity and lipids, whereas density 10 without the biostimulator was favorable for starch, lipids, proteins and productivity. Density 20 with the biostimulator was favorable for lipids.

The lipid and starch characteristics exhibited greater genetic contributions, with a heritability of 49 and 26%, respectively

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

BIBLIOGRAPHIC REFERENCES

Albuquerque, J.A.A., T. Sediyama, A.A. Silva, J.M.A. Alves, E.L. Finoto, F.A. Neto, and G.R. Silva. 2012. Desenvolvimento da cultura de mandioca sob interferência de plantas daninhas. Planta Daninha 30(1), 37-45. Doi: https://doi.org/10.1590/S0100-83582012000100005

Annicchiarico, P. 1992. Cultivar adaptation and recommendation from alfafa trials in Northern Italy. J. Genet. Breed. 46(1), 269-278.

AOAC, Asssociation of Official Analytical Chemists. 2005. Official methods of analysis. 18th ed. Gaithersburg, MD.

Barbosa, M.H., I.R. Carvalho, J.A.G. Silva, D.A. Magano, V.Q. Souza, V.J. Szareski, F. Lautenchleger, D.J. Hutra, N. Moura, and M.V. Loro. 2021. Contribution of the additive genetic effects in soybean breeding aiming at the agronomic ideotype. Funct. Plant Breed. J. 3(1), 1. Doi: https://doi.org/10.35418/2526-4117/v3n1a1

Baretta, D., M. Nardino, I.R. Carvalho, A.C. Oliveira, V.Q. Souza, and L.C. Maia. 2016. Performance of maize genotypes of Rio Grande do Sul using mixed models. Científica 44(3), 403-411. Doi: https://doi.org/10.15361/1984-5529.2016v44n3p403-411

Bester, A.U., I.R. Carvalho, J.A.G. Silva, D.J. Hutra, N.B. Moura, F. Lautenchleger, and M.V. Loro. 2021. Three decades of cassava cultivation in Brazil: Potentialities and perspectives. Rev. Colomb. Cienc. Hortic. 15(2), e12087. Doi: https://doi.org/10.17584/rcch.2021v15i2.12087

Borges, V., P.V. Ferreira, L. Soares, G.M. Santos, and A.M.M. Santos. 2010. Seleção de clones de batata-doce pelo procedimento REML/BLUP. Acta Sci. Agron. 32(4), 643-649. Doi: https://doi.org/10.4025/actasciagron.v32i4.4837

Carvalho, L.P., F.J.C. Farias, C.L. Morello, and P.E. Teodoro. 2016. Uso da metodologia REML/BLUP para seleção de genótipos de algodoeiro com maior adaptabilidade e estabilidade produtiva. Bragantia 75(3), 314-321. Doi: https://doi.org/10.1590/1678-4499.275

Carvalho, I.R., J.A.G. Silva, L.L. Ferreira, V.E. Bubans, M.H. Barbosa, R.B. Mambrin, S.M. Fachi, G.G. Conte, and V.Q. Souza. 2019. Heritability profiles defined by hierarchal models and artificial neural networks for dual-purpose wheat attributes. Genet. Mol. Res. 18(3), gmr18266. Doi: https://doi.org/10.4238/gmr18266

CQFSRS, Comissão de Química e Fertilidade do Solo. 2004. Manual de adubação e calagem para os Estados do Rio Grande do Sul e de Santa Catarina. 10th ed. Sociedade Brasileira de Ciência do Solo, Porto Alegre, Brazil.

Costa, R.B., M.D.V. Resende, A.J. Araújo, P.S. Gonçalves, and N. Bortoletto. 2000. Seleção combinada univariada e multivariada aplicada ao melhoramento genético da seringueira. Pesq. Agropec. Bras. 35(2), 381-388. Doi: https://doi.org/10.1590/S0100-204X2000000200017

Cruz, C.D., P.C.S. Carneiro, and A.J. Regazzi. 2014. Modelos biométricos aplicados ao melhoramento genético. 3th ed. Editora UFV, Viçosa, Brazil.

Facchinello, P.H.K., I.R. Carvalho, E.A. Streck, G.A. Aguiar, J. Goveia, M. Feijó, R.R. Pereira, P.R.R. Fagundes, L.C. Maia, F. Lautenchleger, and A.M. Magalhães Junior. 2021. Gene action and genetic parameters of characters related to rice grain quality. Agron. J. 113, 4736-4752. Doi: https://doi.org/10.1002/agj2.20881

FAO. 2019. Protecting cassava, a neglected crop, from pests and diseases. Rome.

Ferrari, M., I.R. Carvalho, A.J. Pelegrin, V.J. Szareski, M. Nardino, T.C Rosa, N.L. Santos, T.S. Martins, V.Q. Souza, A.C. Oliveira, and L.C. Maia. 2022. Heritability and genetic distance from s1 maize progenies. Commun. Plant Sci. 12, 7-15. Doi: https://doi.org/10.26814/cps2022002

NASSAR, N. M. A. 2006. Mandioca. Ciência Hoje. vol. 39, nº 231.

Oliveira, E.J., F.F. Aud, C.F.G. Morales, S.A.S. Oliveira, and V.S. Santos. 2016. Non-hierarchical clustering of *Manihot esculenta* Crantz germplasm based on quantitative traits. Rev. Cienc. Agron. 47(3), 548-555. Doi: https://doi.org/10.5935/1806-6690.20160066

Oyeyinka, S.A., A.A. Adeloye, O.O. Olaomo, and E. Kayitesi. 2020. Effect of fermentation time on physicochemical properties of starch extracted from cassava root. Food Biosci. 33, 100485. Doi: https://doi.org/10.1016/j.fbio.2019.100485

Pádua, G.J. 2018. Recursos genéticos aplicados ao melhoramento genético de plantas. In: Amabile, R.F., M.S. Vilela, and J.R. Peixoto (eds.). Melhoramento de plantas: variabilidade genética, ferramentas e mercado. Sociedade Brasileira de Melhoramento de Plantas, Brasília, D.F.

Pimentel, A. J. B. Guimarães, J. F. R. Souza, M. A. Resende, M. D. V. Moura, L. M. Rocha, J. R. A. S. C. Ribeiro, G. 2014. Estimação de parâmetros genéticos e predição de valor genético aditivo de trigo utilizando modelos mistos. Pesq. Agropec. Bras. 49(11), 882-890. Doi: 10.1590/S0100-204X2014001100007

Ramalho, M., J.B. Santos, C.B. Pinto, E.A. Souza, F.M.A. Gonçalves, and J.C. Souza. 2012. Genética na agropecuária. 5th ed. UFLA, Lavras, Brazil.

Rosa, T.C, I.R. Carvalho, J.A.G. Silva, V.J. Szareski, T.A. Segatto, E.D. Port, M.V. Loro, H.C.F. Almeida, A.C. Oliveira, L.C. Maia, and V.Q. Souza. 2021. Genetic parameters and multi-trait selection of white oats for forage. Genet. Mol. Res. 20(2), gmr18451. Doi: https://doi.org/10.4238/gmr18451

Santos, H.G. P.K.T. Jacomine, L.H.C. Anjos, V.A. Oliveira, J.F. Lumbreras, M.R. Coelho, J.A. Almeida, J.C. Araujo Filho, J.B. Oliveira, and T.J.F. Cunha. 2018. Sistema brasileiro de classificação de solos. 5th ed. Embrapa, Brasília, DF.

Soxhlet, F. 1879. Die gewichtsanalytische Bestimmung des Milchfettes. Dinglers Polytech. J. 232, 461-465.

Teixeira, P.R.G., A.E.S. Viana, A.D. Cardoso, G.L.P. Moreira, S.M. Matsumoto, and P.A.S. Ramos. 2017. Características físico-químicas de variedades de mandioca de mesa. Rev. Bras. Ciênc. Agrár. 12(2), 158-165. Doi: https://doi.org/10.5039/agraria.v12i2a5433