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Agronomic performance and energy potential of cassava varieties under Amazonian edaphoclimatic conditions

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Abstract. Cassava is a crop that stands out in the Amazon region of Brazil, due to its regional scope and substantial production at the national level. However, the average yield of cassava in Amazonian environments is still considered low. The introduction of new varieties and the development of appropriate techniques for the cultivation of cassava under the edaphoclimatic conditions of the Amazon can improve its yield in the region. The objective of this research was to evaluate the agronomic performance and energy potential of six cassava varieties (BRS Mari, BRS Poti, BRS Formosa, Manivão, Jurará and Coraci) cultivated under Amazonian edaphoclimatic conditions. The study was conducted in Juruti, PA, Brazil and a randomized block design was used, with six blocks and six treatments (varieties), totaling 36 experimental units. The agronomic performance was evaluated based on the emergence index (EI), survival index (SI), plant height (PH), stem diameter (SD), above-ground biomass (Yab), yield of storage roots (Ysr), and harvest index (HI). The energy potential was evaluated based on reducing sugars (RS) and total soluble sugars (TSS). All studied varieties presented satisfactory agronomic performances. The Jurará and Coraci varieties stood out in terms of EI and SI, with average values above 0.9. The Manivão variety showed the highest average values of PH and SD, 2.7 and 0.023 m, respectively, at the end of the evaluation period. The BRS Mari variety had the highest RS content among the studied varieties, while the BRS Formosa variety had the highest TSS, with average values of 2.91 and 2.66%, respectively. All varieties showed an HI above 50%, a Ysr amplitude between 15 and 26 $Mg \cdot ha^{-1}$, and a Yab between 8 and 21 $Mg \cdot ha^{-1}$, indicating good adaptation to Amazonian edaphoclimatic conditions.

Keywords: adaptability, Amazonian environments, bioenergy, *Manihot esculenta* Crantz, yield.

HIGHLIGHTS

1) The Jurará and Coraci varieties stood out in the emergence and survival indices.

2) The cassava varieties evaluated showed a harvest index >50%.

3) The BRS Mari variety had the highest reducing sugar content, while the BRS Formosa variety had the highest total soluble sugar content.

4) The BRS Mari variety had the highest storage root yield with an average of 26 $Mg \cdot ha^{-1}$.

5) The above-ground biomass yield ranged from 8 to 21 $Mg \cdot ha^{-1}$.

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the main food source for more than 800 million people, making it the sixth most important crop globally after wheat, rice, maize, potatoes and barley. World production is estimated at around 315 million tons. Globally, about 63% of cassava is produced in Africa, 28% in Asia and 9% in the Americas. Brazil is the fourth largest producer of cassava in the world, with Nigeria in first place due to its own consumption, followed by Thailand and Indonesia, which export almost all production in the form of starch, pellets and various derivatives to Europe and Asia (FAOSTAT, 2023).

Cassava is used to produce a wide range of products, including starch, starch products, bioethanol and animal feed. The plant is considered one of the crops with the greatest potential to fill the world's food supply gap in the coming years. In addition, cassava can be grown with minimal labor on marginal lands with inconsistent rainfall under low intensity management. In Brazil, cassava performs well in low-fertility soils and in a variety of climates. It has become one of the most popular items in the Brazilian diet since the beginning of colonization. The main cassava product is flour, which can be used by all individuals in the population in various ways, from the simplest everyday dishes to the most sophisticated and refined national cuisine, playing a key role in building cultural identity. It is one of the staple items of the diet of virtually the entire Brazilian population, and arguably the most important food crop, especially for low-income communities (Alves-Pereira et al., 2011; Fiorda et al., 2013; Figueiredo et al., 2014; Somavilla et al., 2022).

The Amazon region that includes the Pará State stands out as one of the largest producers in the national ranking, and 96% of the cassava produced there comes from family farming, which is necessary to guarantee a subsistence living for the families involved in production. However, the average yield of the cassava crop in Amazonian environments is still considered low, less than 15 $Mg \cdot ha^{-1}$. Cassava is one crop that has a very high productive potential, which can reach up to 90 $Mg \cdot ha^{-1}$. The technological level of the local producers is still very low and relatively common practices of soil correction and fertilization are rarely followed. The genetic makeup of the cultivar used often does not reach the productive potential of the region, and the farmers engage in monoculture on a small scale (Silva et al., 2012; Rosa et al., 2014; Filgueiras and Homma, 2016; Brito et al., 2019; Lima et al., 2020).

Some of the factors that contribute to the low yield of the cassava crop are the use of genetic material with low productive potential, inadequate soil management, and lack of effective pest control, as well as prevention of disease and invasive plant takeover. One of the best ways to increase the yield is to choose improved varieties that are productive, resistant to pathogen attacks, and that allow for proper soil management. Therefore, knowing the cassava varieties with the best agronomic performance in a particular region contributes to a better crop yield (Kizito et al., 2007; Farias Neto et al., 2013; Streck et al., 2014; Adiele et al., 2021).

The introduction of new varieties and the development of appropriate techniques for the cultivation of cassava under the edaphoclimatic conditions of each mesoregion constitute the challenges that have to be overcome to improve productivity and quality. The goal is to change farming practices so cassava cultivation stops being just a subsistence crop and becomes a profitable business venture. Such a farm would be capable of supplying not only local demands, but also those of other regions, in addition to generating jobs in the labor market and enhancing the quality of life of the workers. Cassava varieties differ in productivity, both forage and roots, which will allow selection, according to the desired purpose. The regional evaluation of new varieties is necessary since, in the case of cassava, the interaction between the genotype and the environment is very pronounced. Genetic materials already known in other regions are used, which reduces the average time to obtain varieties that meet the specific needs of farmers, as well as cassava processing industries.

Thus, the objective of this research was to evaluate the agronomic performance and energy potential of six cassava varieties, BRS Mari, BRS Poti, BRS Formosa, Manivão, Jurará and Coraci, cultivated under Amazonian edaphoclimatic conditions.

2. MATERIAL AND METHODS

2.1. Location and characterization of the experimental area

The experiments were conducted in Juruti, PA, Brazil, in an agricultural production area located in Esperança community (coordinates 02°19'52"S, 55°58'40"W and 36 m altitude), from December 2021 to November de 2022. The climate in the region, according to the Köppen classification, is of the Am type a monsoon area, characterized by intense rain and very hot weather. The average annual temperature is 26.9 °C, with the highest monthly average temperatures in September and October. Rainfall occurs during all months of the year, but monthly precipitation is highest from December to May. The driest months are August and September, when evapotranspiration was greater than the average monthly rainfall recorded over the last 30 years (Fig. 1A).

Considering the normal climatological characteristics of the region, there is a water surplus from January until the second ten days of June. Thereafter, there is a water deficit until the third ten days of December (Fig. 1B). For a soil with an available water capacity (AWC) of 100 mm, it appears that the soil water storage (SWS) was maximal from the second ten-day period of January to the first ten-day period of June. From then on, the SWS decreased until the first ten days of December, when the normal storage level was restored (Fig. 1C).

The area has a relatively flat, well-drained topography. The soil in the area is of the deep dystrophic yellow latosol type, with a pH of 4.5 and organic matter around 2 dag·dm^{-3}. The chemical characteristics of the soil in the experimental area in the layers from 0 to 0.20 m and from 0.20 to 0.40 m can be seen in Table 1.

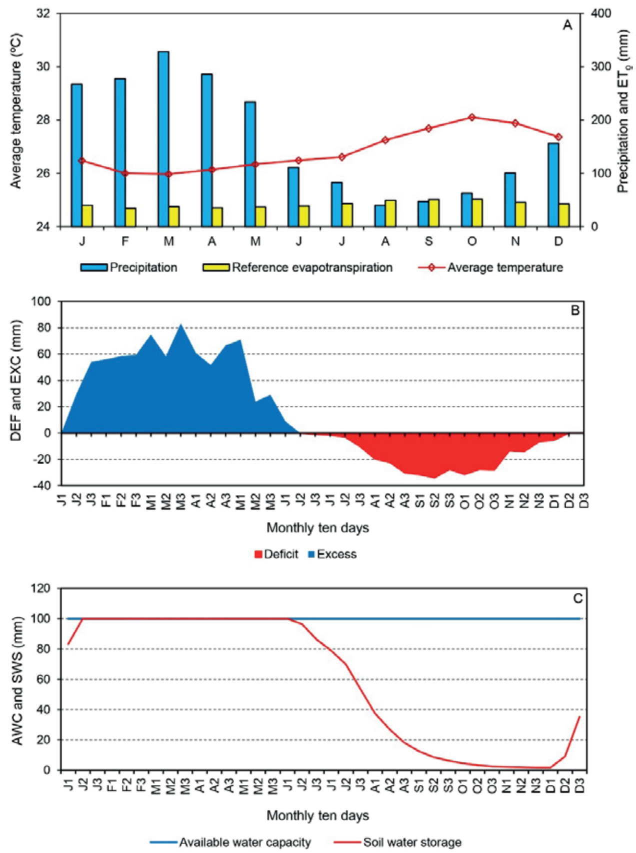

Figure 1. (A) Normal climatological readings for average temperature, precipitation and reference evapotranspiration (ET_o); (B) normal climatological water balance; and (C) normal soil water storage for the region of Juruti-PA, Brazil.

2.2. Implementing and conducting the experiments

An area of 576 m^2 was used for the experiments. The area was limed by the application and incorporation of dolomitic limestone 60 days before the beginning of the experiments. The experimental design adopted was randomized blocks, with six blocks and six treatments (varieties), totaling 36 experimental units. Each experimental unit consisted of 15 plants distributed in three rows with 1 m between rows and 0.8 m spacing between plants. For the agronomic performance evaluations of the varieties, the three central plants of the central row were used, excluding the plants at the ends. The six cassava varieties evaluated were BRS Poti, BRS Mari, BRS Formosa, Jurará, Manivão and Coraci. The genetic materials used in this

Table 1. Chemical analysis (macro- and micro-nutrients) of soil in the experimental area.

Layers	pH	M.O.	Ca	Mg	Al	H+Al	P	K+	B	Zn	Mn	Cu	Fe
meters	H_2O	dag·dm^{-3}		cmol$_c$·dm^{-3}						mg·dm^{-3}			
0 – 0.20	4.5	1.9	0.1	0.1	1.1	6.4	2.7	0.02	0.2	0.1	0.6	0.1	158
0.20 – 0.40	4.5	2.6	0.1	0.1	1.3	6.5	3.9	0.02	0.3	0.2	0.5	0.1	130

pH - hydrogen potential; M.O. - organic matter; P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium; H+Al - hydrogen + aluminum; Cu - copper; Fe - iron; Zn - zinc; Mn - manganese; B - boron.

research come from the germplasm bank located in the municipality of Tracuateua, PA, Brazil, with the exception of the Coraci variety, which has been widely cultivated in the municipality of Juruti, PA, Brazil, for a long time.

The planting holes were made with a hoe, similar to the way used by local farmers. The cuttings for planting were made at a right angle with a machete, allowing the distribution of the roots in a more uniform way than a bevel cut. The cuttings were planted manually in the holes in a horizontal position, at a depth of approximately 0.10 m.

Before planting, 50 g of single superphosphate fertilizer (18% P_2O_5) was applied per hole. At 40 and 70 days after planting (DAP), the soil was top-dressed with 40 g of 20-0-20 fertilizer per hole. The management of pests, diseases and invasive plants was carried out in accordance with the agronomic recommendations for the cultivation of cassava in a planting system used in family farming.

2.3. Agronomic performance evaluations

Different methods of evaluating the agronomic performance of the cassava varieties studied were carried out. For the emergence index (EI), the number of plants that emerged in each plot at 30 DAP was counted, and then expressed as a ratio of the number of cutting planted, according to equation 1:

$$EI = \left(\frac{Pe}{Pst}\right) \quad (1)$$

where EI is the emergence index, Pe is the number of plants that emerged and Pst is the number of cuttings planted.

The survival index (SI) was evaluated by counting the number of plants that survived in each plot at the end of the evaluation period as a ratio of the number of cuttings planted, according to equation 2:

$$SI = \left(\frac{Ps}{Pst}\right) \quad (2)$$

where SI is the survival index, Ps is the number of plants that survived and Pst is the number of cuttings planted.

Plant height (PH) was measured monthly, with the first measurement performed at 30 DAP. PH data were obtained with the aid of a ruler and a measuring tape attached to a piece of wood, adopting the distance between the plant collar and the apical bud of the main branch as the criterion. For the stem diameter (SD), the measurements started at 90 DAP, because some plants did not reach a height of 0.10 m. Measurements were performed using a digital caliper.

The above-ground biomass was obtained by weighing all the material collected from the neck of the plant to the highest point. Storage root biomass was determined by weighing the roots of usable plants in a plot. The weighing procedure was carried out in the experimental area with the aid of a digital electronic scale and a portable power generator. Conversions of above-ground and storage root biomass to yield values were performed using Equations 3 and 4.

$$Yab = \left(\frac{By\ Pn}{1000}\right) \quad (3)$$

where Yab is the aerial biomass yield in $Mg{\cdot}ha^{-1}$, By is the above-ground biomass in kg of the useful plants in the plot and Pn is the number of plants per hectare for a spacing of 1.0 x 0.8 m.

$$Ysr = \left(\frac{Bsr\ Pn}{1000}\right) \quad (4)$$

where Ysr is the yield of storage roots in $Mg{\cdot}ha^{-1}$, Bsr is the storage root biomass of useful plants in the plot in kg and Pn is the number of plants per hectare considering the spacing of 1.0 x 0.8 m.

The harvest index (HI) was calculated as the ratio of the storage root biomass to total plant biomass (storage root biomass + above-ground biomass) using equation 5:

$$HI = \left(\frac{Bsr}{Bt}\right) \quad (5)$$

where HI is the harvest index, Bsr is the storage root biomass of the plot's useful plants in kg, and Bt is the total plant biomass in kg.

The percentage of reducing sugars (RS) was determined by the dinitrosalicylic acid (DNS) method (Miller, 1959) and the percentage of total soluble sugars (TSS) by the anthrone method (Morris, 1948; Yemm and Willis, 1954). Absorbance values were obtained using a UV-Vis spectrophotometer.

2.4. Data analysis

The F test was used to verify significant differences between treatments and the Tukey test at 5% probability to compare means. Analysis of variance and comparison of means were performed using the Sisvar software, version 5.8.

3. RESULTS AND DISCUSSION

3.1. Predominant environmental conditions

The predominant environmental conditions in the research period (December 2021 to November 2022) are shown in Figure 2. The monthly averages of maximum and minimum temperature did not show significant vari-

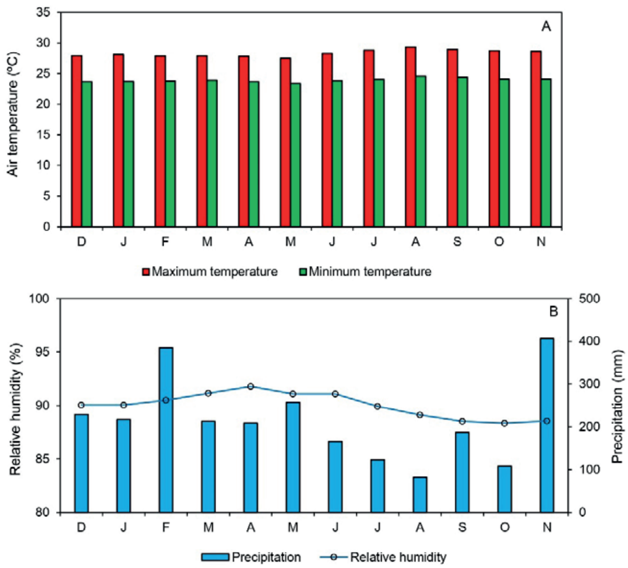

Figure 2. Monthly averages of meteorological variables (maximum and minimum temperature, relative humidity) and total monthly precipitation obtained in the region of Juruti-PA, Brazil, from December 2021 to November 2022.

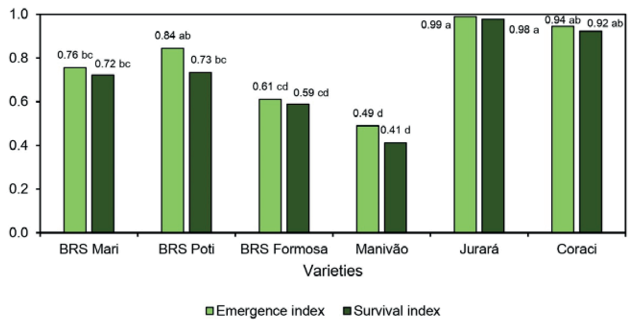

Figure 3. Emergence and survival indices of cassava varieties cultivated in the Juruti-PA region, Brazil. Different letters indicate significant differences between experimental means at the 5% probability level by Tukey's test.

ations within the analysis period. The monthly maximum temperature was around 28 °C and the monthly minimum temperature was around 24 °C. The small variation in monthly average values of maximum and minimum temperature throughout the year is common in equatorial or low-latitude regions. The geographic location of the region of Juruti-PA, Brazil implies a minimization of the effects of the inclination of the Earth's axis in relation to the sun, characterizing a climate pattern in which there are no significant environmental variations between the seasons.

Monthly precipitation was higher in February and November 2022, with totals of 385 and 406 mm, respectively. The months with the lowest values of monthly precipitation totals were August and October 2022, with 83 and 108 mm, respectively. Accumulated precipitation during the research period was 2582 mm, which was higher than the normal annual average for the region. The monthly averages of relative air humidity were around 90% throughout the research period. The registered environmental conditions were characteristic of the predominant climate in the Amazon region, which is classified as humid equatorial.

3.2 Emergence and survival indices, plant height and main stem diameter

The cassava varieties that showed the lowest EI were Manivão and BRS Formosa with values of 0.49 and 0.61, respectively (Fig. 3). The other studied varieties had EIs >0.75, with the Jurará variety showing an EI of 0.99. As for the SI values, the lowest performance was found for the Manivão and BRS Formosa varieties, with values of 0.41 and 0.59, respectively. The other varieties studied had SIs >0.70, again highlighting the Jurará variety, which had a SI of 0.98.

PH values varied according to the variety (Table 2). In the first month of the evaluation period, BRS Poti had the highest PH value at 0.12 m. At the end of the evaluation period, the Coraci, BRS Mari and Manivão varieties showed the highest PH values at 2.15, 2.40 and 2.70 m, respectively. The BRS Formosa, BRS Poti and Jurará varieties showed PH values < 2 m at the end of the evaluation period. PH is an important variable for deter-

Table 2. Plant heights (meters) of cassava varieties throughout the growing season.

Date	Variety					
	BRS Mari	BRS Poti	BRS Formosa	Manivão	Jurará	Coraci
Jan 19	0.07 b	0.12 a	0.08 b	0.07 b	0.08 b	0.08 b
Feb 19	0.19 a	0.21 a	0.18 a	0.19 a	0.19 a	0.20 a
Mar 27	0.52 a	0.52 a	0.50 a	0.65 a	0.61 a	0.56 a
Apr 24	0.79 a	0.74 a	0.72 a	0.96 a	0.82 a	0.83 a
May 21	1.03 a	0.94 a	0.93 a	1.29 a	1.03 a	1.08 a
Jun 19	1.22 ab	1.09 b	1.12 b	1.64 a	1.18 ab	1.33 ab
Jul 24	1.54 ab	1.25 b	1.23 b	1.94 a	1.40 b	1.58 ab
Aug 20	1.78 ab	1.41 b	1.37 b	2.14 a	1.57 b	1.78 ab
Sep 24	2.04 ab	1.59 bc	1.53 c	2.40 a	1.75 bc	1.92 abc
Oct 22	2.24 ab	1.75 bc	1.60 c	2.56 a	1.85 bc	2.06 abc
Nov 19	2.40 ab	1.91 bc	1.67 c	2.70 a	1.94 bc	2.15 bc

Different letters on the same line mean significant differences between varieties using Tukey's test ($p < 0.05$).

Table 3. Stem diameters (meters) of cassava varieties throughout the growing season.

Date	BRS Mari	BRS Poti	BRS Formosa	Manivão	Jurará	Coraci
Feb 19	0.002 a	0.003 a	0.003 a	0.003 a	0.004 a	0.003 a
Mar 27	0.007 a	0.008 a	0.008 a	0.010 a	0.010 a	0.009 a
Apr 24	0.010 a	0.010 a	0.011 a	0.013 a	0.012 a	0.011 a
May 21	0.012 a	0.011 a	0.013 a	0.015 a	0.013 a	0.013 a
Jun 19	0.014 a	0.012 a	0.014 a	0.016 a	0.014 a	0.014 a
Jul 24	0.015 ab	0.012 b	0.015 ab	0.018 a	0.014 ab	0.015 ab
Aug 20	0.016 ab	0.013 b	0.015 ab	0.019 a	0.015 ab	0.016 ab
Sep 24	0.018 ab	0.013 b	0.017 ab	0.021 a	0.016 ab	0.017 ab
Oct 22	0.020 a	0.014 b	0.017 ab	0.022 a	0.017 ab	0.018 ab
Nov 19	0.021 ab	0.015 c	0.018 abc	0.023 a	0.017 bc	0.018 abc

Different letters on the same line mean significant differences between varieties using Tukey's test ($p < 0.05$).

mining spacing, for choosing varieties that can be used in a consortium and for weed management (Rós et al., 2011). Thus, the Coraci, BRS Mari and Manivão varieties showed excellent soil coverage, which reduced takeovers by invasive plants. In addition, these varieties were promising as suppliers of cuttings for mechanized planting, since the larger the branch, the greater the operational yield of the planting machine (Vidigal Filho et al., 2000; Borges et al., 2002; Azevedo et al., 2006). The BRS Formosa, BRS Poti and Jurará varieties showed a low yield of stem cuttings, in addition to hampering cultivation practices such as weeding and fertilization.

Stem diameter values did not show significant differences between the cassava varieties studied until the sixth month of evaluation (Table 3). After the sixth month, significant differences were observed between the cassava varieties studied. At the end of the evaluation period, the BRS Mari and Manivão varieties had the highest SD values at 0.021 and 0.023 m, respectively. At the end of the evaluation period, the BRS Poti, BRS Formosa, Jurará and Coraci varieties had SD values that were <0.02 m.

3.3. Yield and energy potential of cassava varieties

The cassava varieties studied showed significant differences in above-ground biomass yield (Yab). The Manivão variety had the highest average Yab at 21 Mg·ha^{-1}, while BRS Poti showed the lowest average Yab, 8 Mg·ha^{-1}. The BRS Mari, BRS Formosa, Jurará and Coraci varieties showed average Yab values of 15, 14, 10 and 15 Mg·ha^{-1}, respectively (Fig. 4). The Yab performance of the Manivão variety revealed its potential for use in animal feed and to minimize costs for the acquisition and transport of propagation material.

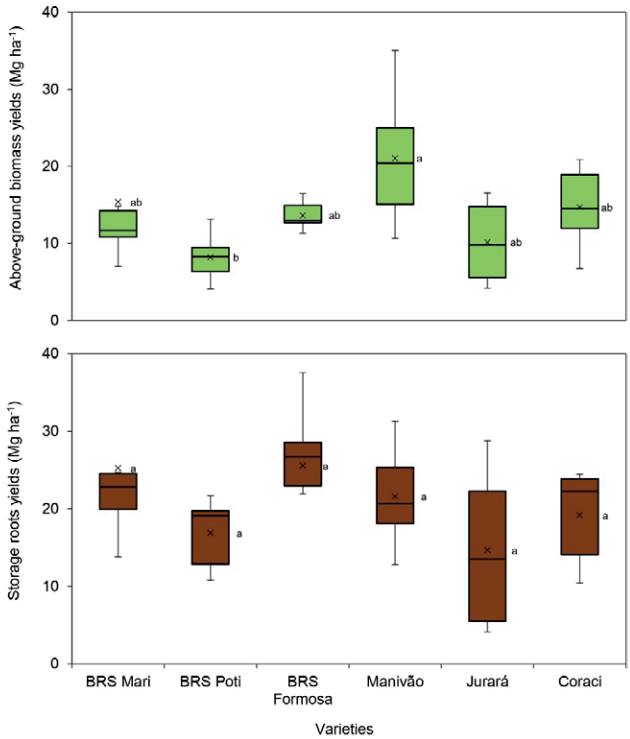

Figure 4. Above-ground biomass and storage root yields of cassava varieties cultivated in the Juruti-PA region, Brazil. Different letters indicate significant differences between experimental means at the 5% probability level by Tukey's test.

With regard to the storage root yield (Ysr), the cassava varieties studied did not show significant differences. The average values of Ysr for the BRS Mari, BRS Poti, BRS Formosa, Manivão, Jurará and Coraci varieties were 26, 17, 26, 22, 15 and 19 Mg·ha^{-1}, respectively. The Ysr of these varieties was greater than or equal to the average yield recorded in Brazil in 2021, which was 15 Mg·ha^{-1} (FAOSTAT, 2023). The results showed a range of Ysr of 15 to 26 Mg·ha^{-1}for the genetic materials evaluated, showing that the replacement of varieties in use by farmers could increase the cassava crop yield in the Amazon region.

Considering the harvest index, the cassava varieties studied showed significant differences between them (Fig. 5). The varieties that presented the highest average HI values were BRS Mari (0.64), BRS Poti (0.68) and BRS Formosa (0.64). The varieties that presented the lowest average HI values were Manivão (0.52), Jurará (0.56) and Coraci (0.57). The HI reflects the efficiency of the varieties in root production, identifying those with the greatest capacity to

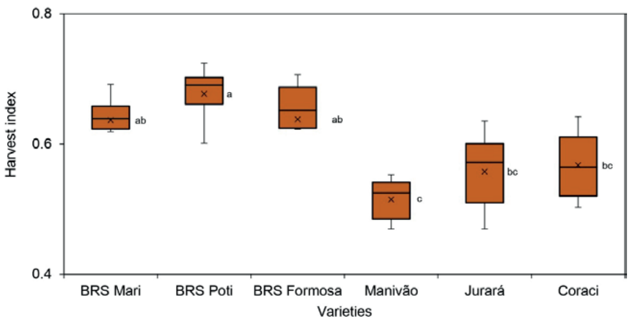

Figure 5. Harvest index of cassava varieties cultivated in the Juruti-PA region, Brazil. Different letters indicate significant differences between experimental means at the 5% probability level by Tukey's test.

direct the carbohydrates produced in the leaves to the production of roots (Silva et al., 2021). According to Peixoto et al. (2005), the harvest index is considered satisfactory when it exceeds 50%. Thus, all varieties evaluated in this research presented satisfactory values.

The BRS Mari variety had the highest RS value (2.91%) followed by the Coraci variety (2.41%). The BRS Formosa (2.34%), Jurará (2.33%) and Manivão (2.31%) varieties were statistically equal (Fig. 6). Bezerra et al. (2002) stated that the sugar content in the cassava roots could be influenced by the harvest time and the storage period, but mainly by the variety. The BRS Poti variety had the lowest RS value (1.55%). In terms of TSS, the BRS Formosa variety had the highest values (2.66%), followed by th BRS Mari variety (2.56%), BRS Poti (2.41%), Jurará (2.33%), Coraci (2.31%) and Manivão (1.91%).

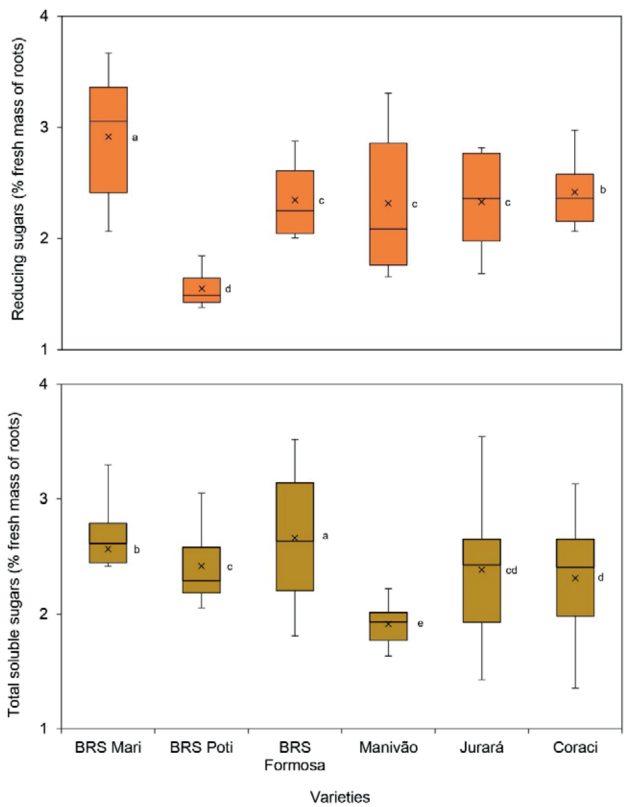

Figure 6. Reducing sugars and total soluble sugars of cassava varieties cultivated in the Juruti-PA region, Brazil. Different letters indicate significant differences between experimental means at the 5% probability level by Tukey's test.

4. CONCLUSIONS

The cassava varieties BRS Mari, BRS Poti, BRS Formosa, Manivão, Jurará and Coraci showed a satisfactory agronomic performance when cultivated in Amazonian edaphoclimatic conditions. The Jurará and Coraci varieties stood out in terms of emergence and survival indices, with average values above 0.9 for these two variables. The Manivão variety had the highest average values for plant height and stem diameter at the end of the evaluation period, 2.7 and 0.023 m, respectively.

The BRS Mari variety had the highest reducing sugar content among the studied varieties, while the BRS Formosa variety had the highest total soluble sugar content, with average values of 2.91 and 2.66%, respectively. All cassava varieties evaluated had a HI >50%, a range of storage root yields between 15 and 26 Mg·ha^{-1}and aboveground biomass yields between 8 and 21 Mg·ha^{-1}, indicating good potential for the dual purpose of shoots and roots production, with good adaptation to the Amazonian edaphoclimatic conditions, thus, these varieties represent good options for rural producers in this region.

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