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Scientific Article

Early evaluation of genotype x harvest interactions in cassava crops under water stress

Avaliação precoce da interação genótipo x safras na cultura da mandioca sob déficit hídrico

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ABSTRACT - The aim of this study was to evaluate the effect of genotype x harvest interactions on different agronomic traits, the genetic correlation between traits in early selection under water stress, and early selection in cassava. 25 cassava genotypes were evaluated in a randomized block experimental design with four replications. The variables root weight (RW), root number per plant (RN), root diameter (RD), root length (RL), root dry matter content (DMC), stem number per plant (SN), plant height (PH), stem diameter (SD), mite severity (MS), and harvest index (HI) were evaluated under water stress conditions in two harvests. Broad-sense heritability (h^2), realized heritability (h_R^2), and the index of coincidence (IC) were estimated. Accuracy estimates ranged from 0.62 for RL to 0.86 for DMC. A significant genotype effect was identified on all traits, except for RW, RL and SD. Significant genotype x harvest interactions occurred for the variables SN, PH, SD, and HI. (h^2) estimates ranged from 0.27 for RL to 0.79 for SN. The estimates of the index of coincidence ranged from 100% to 25%. A positive correlation was observed between all variables under study, except for MS, RN and SN, and the other traits. The genotypes showed similar performance in the two harvests for most variables, except for SN, PH, SD, and HI.

Keywords: Genetic improvement. Realized heritability. Genetic correlation.

RESUMO - O objetivo deste trabalho foi avaliar a interação genótipos x safras de diferentes caracteres, a correlação genética entre caracteres agronômicos na seleção precoce sob déficit hídrico, bem com avaliar a seleção precoce desses caracteres. Foram avaliados 25 genótipos de mandioca em delineamento experimental de blocos completos casualizados com quatro repetições. As variáveis peso de raízes (RW); número de raízes por planta (RN); diâmetro de raiz (RD); comprimento de raiz (RL); teor de matéria seca das raízes DMC; número de hastes por planta (SN); altura de plantas (PH); diâmetro de caule (SD); severidade de ácaros (MS); índice de colheita (HI) foram avaliadas sob condições de déficit hídrico em duas safras. Foram estimadas ainda herdabilidade no sentido amplo (h^2) herdabilidade realizada (h_R^2), bem como o índice de coincidência (IC). As estimativas de acurácia variaram de 0,62 para RL a 0,86 para DMC. Foi possível identificar efeito significativo de genótipos para todos os caracteres, exceto para RW, RL e SD. Ocorreu interação genótipos x safras significativas para as variáveis SN, PH, SD e HI. As estimativas de (h^2) variaram de 0,27 para RL a 0,79 para SN. As estimativas de índice de coincidência variaram de 100% a 25%. Foi observada correlação positiva entre todas as variáveis avaliadas, exceto MS, RN e SN com os demais caracteres. Os genótipos apresentaram desempenho coincidente nas duas safras para maioria das variáveis exceto para SN, PH, SD e HI.

Palavras-chave: Melhoramento genético. Herdabilidade realizada. Correlação genética.

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INTRODUCTION

Water stress is an abiotic stress that causes major losses in agricultural production (FAHAD et al., 2017). According to Daryanto, Wang and Jacinthe (2017), the intensification of climate change observed in recent years has contributed to this factor, especially in more sensitive areas, such as the semi-arid region, raising concerns about food security. These concerns are no different for cassava because this crop is crucial for food security in African, Asian, and South American countries (MIRANDA et al., 2020). Developing and growing tolerant and high-yielding varieties has been indicated as one of the main strategies for mitigating this problem (VITOR et al., 2019; ADU, 2020; OREK et al., 2020). However, in cassava improvement programs, characteristics such as yield are frequently evaluated very late, often leading to deviations from modern improvement goals (ADU, 2020), such as eliminating genotypes with undesirable characteristics as early as possible, which implies reducing time, effort, consumables, and planting area in successive crop generations.

To develop cultivars tolerant to water stress, genetic improvement programs have performed field tests with germplasm under water stress conditions towards identifying and selecting tolerant and more responsive varieties. Such studies are crucial for following genomic evolution while simultaneously continuing to produce practical results in increasing yield (VITOR et al., 2019). Different agronomic descriptors have been evaluated as indicators of water stress tolerance, such as dry matter content, shoot weight and root yield, among others. Evaluating mite resistance is also highly important because mites are among the most important pests for the crop in the country, especially in the Northeast region, where they attack particularly in the dry seasons. However, evaluations under water stress conditions remain mostly overlooked in the literature. Identifying mite-resistant genotypes through phenotypic selection requires dry environmental conditions that favor pest infestation (EZENWAKA et al., 2018).

Efficient genetic improvement programs aimed at selecting genotypes based on quantitative characteristics must collect data on the extent and nature of genetic variation, heritability, possible occurrences of genotype x environment interactions, as well as their magnitudes in different traits, and correlations, and predict genetic advance through selection (FEHR, 1987).

Heritability is a parameter that allows breeders to assess the possibility of success by selection, as reflected in the proportion of phenotypic variation that can be inherited (RAMALHO et al., 2012a). In addition, understanding the genetic association between traits may help to define the most appropriate selection method and the traits that can be gained through selection (OLIVEIRA et al., 2015). Studies of genotype x environment interactions provide information on the predictability of the behavior of genotypes under changes in uncontrollable factors.

Considering the above, the aim of this study was to evaluate, early, the effect of the genotype x harvest interactions, the genetic correlation between traits of the cassava crop under water stress, and the early selection of these traits.

MATERIAL AND METHODS

Two experiments were performed from November 2018 to February 2020, in the vegetable production sector of the Federal University of Vale do São Francisco (*Universidade Federal do Vale do São Francisco* – UNIVASF), at the Agricultural Sciences Campus (*Campus Ciências Agrárias*), located in the municipality of Petrolina - Pernambuco (PE), whose geographic coordinates are 9º16’10” S and 40º33’43” W at an average altitude of 373 m. The climate of the region according to Köppen’s climate classification is hot semi-arid, Bsh’, characterized by scarce and irregular precipitation, with summer rains and strong evaporation as a result of high temperatures. The soil is classified as Alfisol (*Argissolo Amarelo Eutrocoeso Típico*) by Silva et al. (2017).

The two tests were performed in a randomized block design (RBD), with four replicates. The plots consisted of a row with seven plants each, spaced 1.0 m x 0.8 m. The 25 accessions were obtained from the Cassava Germplasm Bank (*Banco de Germoplasma de Mandioca* – BGM) of the Brazilian Agricultural Research Corporation (*Empresa Brasileira de Pesquisa Agropecuária* – EMBRAPA) Cassava and Fruits - Cruz das Almas, Bahia (BA), Brazil. Table 1 shows the cassava variety used in both experiments.

Table 1. Cassava varieties and type classification.

Genotypes	Type	Origin		
2011-24-156	Improved	Cruz das Almas	BA	Brazil
2011-34-41	Improved	Cruz das Almas	BA	Brazil
BGM-0164	Local variety	Cruz das Almas	BA	Brazil
BGM-0170	Local variety	-	-	Brazil
BGM-0303	Local variety	Cali	Valle del Cauca	Colombia
BGM-0396	Local variety	-	ES	Brazil
BGM-0512	Local variety	Divinópolis	MG	Brazil
BGM-0648	Local variety	Pentecoste	CE	Brazil
BGM-0808	Local variety	Chá do Pilar	AL	Brazil
BGM-1243	Local variety	Cali	Valle del Cauca	Colombia
BGM-1267	Local variety	Petrolina	PE	Brazil
BGM-1726	Improved	Cruz das Almas	BA	Brazil
BGM-2100	Local variety	Marechal	PR	Brazil
BRS Caipira	Improved	Cruz das Almas	BA	Brazil
BRS Dourada	Local variety	São Felipe	BA	Brazil
BRS Formosa	Improved	Cruz das Almas	BA	Brazil
BRS Gema de Ovo	Local variety	-	AM	Brazil
BRS Jari	Improved	Cruz das Almas	BA	Brazil
BRS Kiriris	Improved	Cruz das Almas	BA	Brazil
BRS Mulatinha	Improved	Cruz das Almas	BA	Brazil
BRS Poti Branca	Improved	Cruz das Almas	BA	Brazil
BRS Tapioqueira	Improved	Cruz das Almas	BA	Brazil
BRS Verdinha	Improved	Cruz das Almas	BA	Brazil
Capixaba	Local variety	Petrolina	PE	Brazil
TME-14	Improved	Kampala	-	Uganda

The area was tilled using a leveling disc harrow to open 10 cm deep longitudinal planting furrows across the area, with no need for supplementary fertilization. Manual weeding was performed as needed during both tests. A drip system was used for irrigation, and during the first two months the amount of water was supplied three times per week based on rainfall and evapotranspiration measurements from previous days. The amount of drip irrigation was 50% and 75% of crop evapotranspiration (ET_c) during the third and fourth months, respectively, in both experiments (Figure 1). After that period, the irrigation water supply was suspended until harvest. The total amount of irrigation water was 312,5 mm in the first experiment and 304 mm in the second.

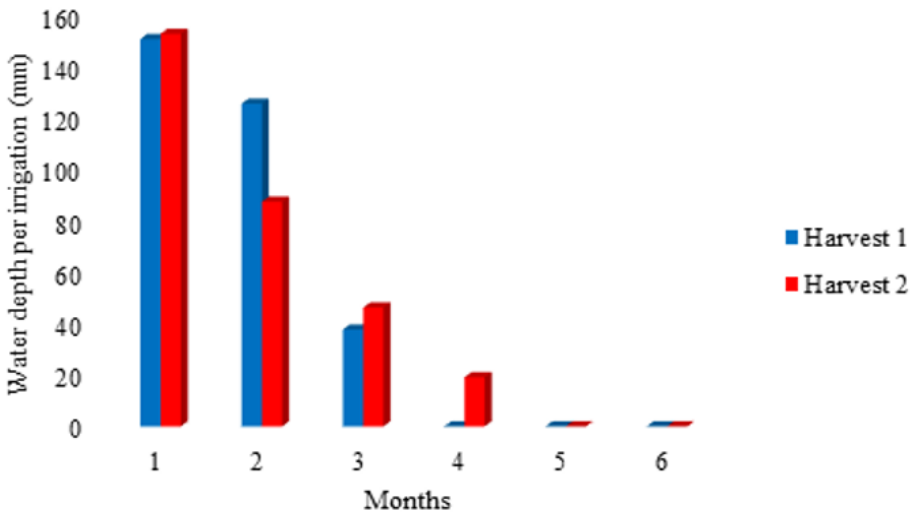

Figure 1. Water depth per irrigation between November/2018 and April/2019 (Harvest 1) and August/2019 and January/2020 (Harvest 2).

The average temperature during the two experiments was 27 ºC, with 57 and 51% relative air humidity, and 267.0 mm and 133.9 mm total precipitation, respectively (Figure 2). For the first and second harvests, total depths of 312 mm and 304 mm, respectively, were applied (Figure 1).

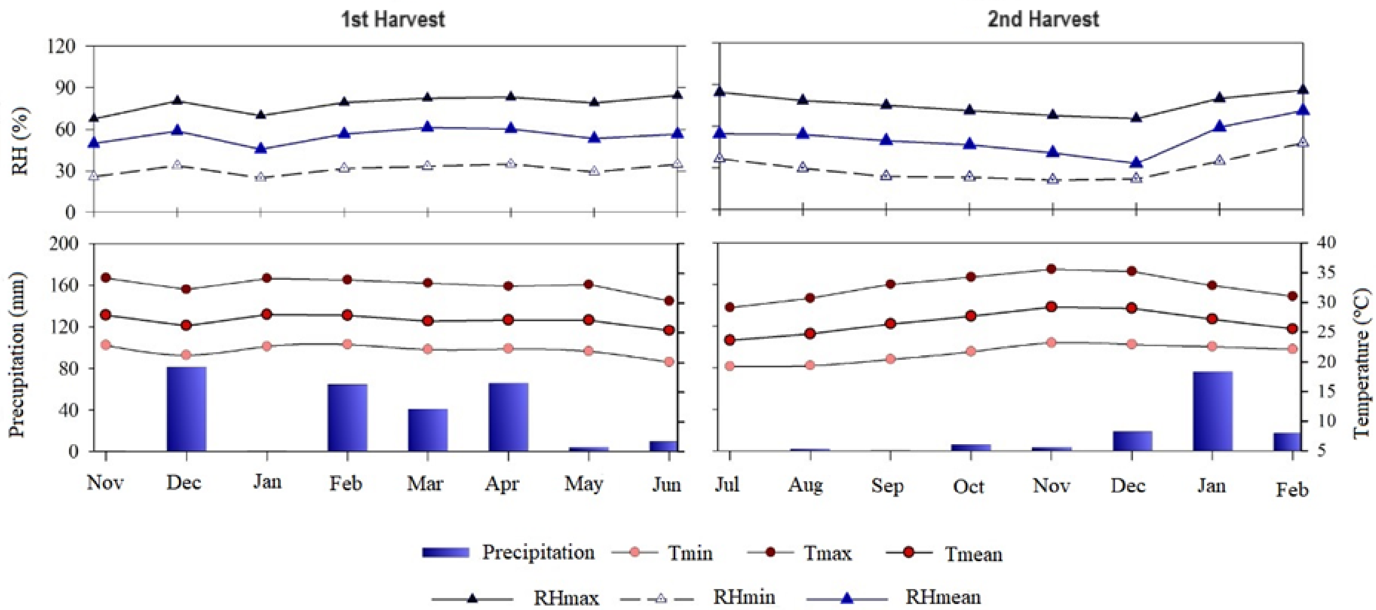

Figure 2. Climatic data of precipitation, temperature, and humidity for the 2018/19 and 2019/20 harvests, Petrolina, PE, Brazil.

Approximately 6 months after planting (188 days and 193 days), in the usable area of each plot, three plants were sampled in both experiments. First, the following parameters were assessed: plant height (PH, in m), from the soil to the stem apex; above-ground stem number per plant (SN); and stem diameter (SD, in mm) at 20 cm from the soil. During the harvest, three plants were collected to measure root number per plant (RN), root length (RL, in cm), root diameter (RD, in mm), measured in the medial section of the roots, root weight (RW, in kg per plot), and shoot weight (SW, in kg per plot).

The root dry matter content (DMC, in %) was estimated in a homogeneous sample of 0.5 kg roots cut into slices and dried to constant weight.

The harvest index (HI in %) was measured as proposed by EWA et al. (2017):

$$HI = RW/(RW + SW).100$$

where in:
RW: Total root weight;
SW: Total shoot weight.

Mite severity (MS) was assessed using the following scale of scores: (1) absence of mites; (2) small spots in a few leaves, (3) many spots, with leaf area already reduced due to the attack; (4) symptoms of mite attack to the plant apex, with a decrease in internode number and a marked decrease in leaf number; (5) young shoots with candlestick appearance and curved apex and completely defoliated plant (IITA, 1990).

The components of variance were estimated by restricted maximum likelihood (REML), and the genotypic values were predicted by best linear unbiased prediction (BLUP). Random effects of the model were tested by analysis of deviance (ANADEV) using the likelihood-ratio test (LRT). In the model, genotypic effects were considered random and year effects were fixed. The harvest effect was tested by type III analysis of variance (ANOVA) using the package “lme4” of the software R version 3.4.4 (R CORE TEAM, 2022).

The experimental accuracy was assessed by estimating the selective accuracy (RESENDE; DUARTE, 2007):

$$Ac = (1 – PEV/\alpha^2_g)$$

where:
PEV: Prediction error variance;
α^2_g: Genotypic variation.

To estimate the efficiency of the early selection of genotypes for the traits evaluated in the two harvests, the index of coincidence was estimated using the equation proposed by Hamblin and Zimmermann (1986):

$$IC = (A – C)/(M – C).100$$

where:
A: Number of selected superior genotypes common to both harvests;
M: Number of superior genotypes selected in one of the harvests;
C: number of randomly selected superior genotypes. A selection intensity of 20% was used. Then, of the 5 selected genotypes, the number of genotypes that will randomly coincide will be 1.

The realized heritability by variable was also estimated as proposed by Fehr (1987) and adapted by Ramalho et al. (2012b):

$$h^2_R = ((mjki - mki)/mki)/((msji - mji)/mji)$$

h^2_R: realized heritability by trait;
mjki: mean in generation *k* of genotypes *i* selected in generation *j*;
mki: overall mean of genotypes *i* in generation *k*;
msjl: mean of genotypes *i* selected in generation *j;*
mji: overall mean of genotypes *i* in generation *j*; $k > j$.

Principal component analysis (PCA) was performed for the variables under study using the package “prcomp” of the software R version 3.4.4 (R CORE TEAM, 2022).

RESULTS AND DISCUSSION

The accuracy estimates ranged from 0.62 for RL to 0.86 for DMC (Table 2). According to Resende and Duarte (2007), these estimates indicate moderate and high experimental accuracy, respectively. The likelihood tested indicated a significant difference between genotypes for the variables SW, RN, RD, DMC, SN, PH and HI, but not for RW, RL, SD and MS (Table 2). Significant effects indicate genetic variability for these traits, which is crucial for genetic improvement programs aimed at developing cultivars tolerant and responsive to water stress because each genotype may show desirable aspects in some of the significant characteristics. Nonsignificant genotypic effects observed in these four variables indicate that all genotypes had similar responses, which means that the genotype selection should not be based only on these traits. In addition, although the genotypes used in the present study represented a sample of the local varieties and cultivars, which are mostly considered adapted to semi-arid conditions, they may not have had enough time to express their genetic potential. El-Sharkawy (2007) argues that the tuberization process intensifies between 6 and 10 months after planting. Thus, the effect of genotypes for RW observed in the present study may also have been influenced by the season of evaluation of this variable. The overall mean yield assessed in the test was significantly higher than values found by Oliveira et al. (2021), thus indicating that the genotypes evaluated in the present study are well adapted to water stress conditions.

The nonsignificant effect of genotypes for MS shows the difficulty in identifying sources of resistance to the attack by this arthropod, especially when showing high root yields. Similar results were found by Strucker et al. (2017) when evaluating oviposition preference in different seasons for the BRS Jari variety, which showed a high concentration of eggs per cm^2.

Table 2. Summary of the significance test, mean and selective accuracy: SW - shoot weight (t ha^{-1}); RW – root weight (t ha^{-1}); RN - root number per plant; RD - root diameter in mm; RL - root length in cm ; DMC – root dry matter content; SN - stem number per plant; PH - plant height in m; SD - stem diameter in mm; MS - mite severity; harvest index - HI of the 25 cassava genotypes under water stress conditions throughout two harvests in Petrolina, PE, Brazil.

Effect	Component of Variance (1)										
	SW	RW	RN	RD	RL	DMC	SN	PH	SD	MS	HI
Genotype (G)	3.698*	1.064	1.175*	72581*	1.998	6.036*	0.3583*	170.8*	18177	0.01881	24.11*
G x S	0	0.797	0.3573	12594	0.964	1.780	0.1932*	134.5*	24011*	0.00291	13.49*
Residual	16.118	4.768	3.8861	339670	21.3881	10.001	0.3882	365.1	67363	0.20606	49.73
	FC value (2)										
Harvest (S)	9.89*	4.91*	16.04*	2.69	18.55*	43.78*	7.40*	0.267	15.42*	21.54*	35.12*
Overall $\bar{X}$f	19.23	8.02	7.17	3.26	27.64	23.31	2.63	146.24	2.21	3.94	28.46
Ac	0.80	0.72	0.80	0.77	0.62	0.86	0.84	0.78	0.67	0.64	0.81

(1) Maximum Likelihood Ratio; (2) type III ANOVA * significant at 5% probability level; $\bar{X}$f: overall mean of the variable; Ac: selective accuracy.

Significant genotype x harvests interactions demonstrated that at least one genotype expressed differently between harvests for the variables SN, PH, SD and HI (Table 3). All these variables are related to above-ground vegetative traits, which showed that the decrease in water availability started causing a deleterious effect on vegetative growth. The variables related to roots did not show significant differences between harvests. According to El-Sharkawy (2007), cassava plant has different strategies to mitigate the effects of water stress, such as investing in a deeper root system, showing a high recovery capacity reaching its maximum biomass production after rehydration, and a rapid formation of new leaves with a high photosynthetic rate immediately after stress. Thus, the rainfall amount that occurred after the fourth month of the experiment during the second cropping cycle has contributed to promoting vegetative growth. However, it was not enough to promote a significant root development change between production cycles because of the short time. This study focused on cassava as a staple food and industrial purposed (starch production). Then, the differences on SN, PH, SD and HI between harvests could make the selection of promising genotypes more difficult for plant breeders who focus on cassava hay as animal feed. Because genotype x harvest interactions are complex, the ranking of genotypes varies with the environments under study, hindering selection and general recommendations by plant breeders (KORTE et al., 2020).

Table 3. Estimates of broad-sense heritability (h^2), realized heritability (h_R^2) and Index of coincidence (IC) of the 25 cassava genotypes under water stress conditions throughout two harvests in Petrolina, PE, Brazil.

Parameters	SW	RW	RN	RD	RL	DMC	SN	PH	SD
h^2	0.48	0.47	0.53	0.46	0.27	0.71	0.79	0.65	0.52
h_R^2	0.40	0.13	0.73	0.22	0.51	0.69	0.91	0.05	0.54
IC (%)	100	50	50	75	25	75	50	50	75

SW - shoot weight (t ha^{-1}); RW – root weight (t ha^{-1}); RN - root number per plant; RD - root diameter in mm; RL - root length in cm; DMC – root dry matter content; SN - stem number per plant; PH - plant height in m; SD - stem diameter in mm.

In the present study, a significant difference was also observed in the harvest effect for all variables under study, except for RD and PH. Figure 2 shows different conditions of occurrence of monthly precipitation indices between the two harvests. Rainfall was higher in the first harvest and approximately twice that observed in the second harvest. Conversely, the second harvest showed a higher occurrence of rainfall in the last three months. These differences in rainfall events and humidity may have contributed to the expression of significant differences in the harvest effect assessed in the present study. Similar precipitation conditions were assessed during experiments conducted by Oliveira et al. (2017) in Petrolina-PE.

The irrigation management conditions imposed by the authors and the precipitation assessed in the study made it possible to identify that all genotypes were tolerant to water stress, as well as the magnitude of correlations between traits evaluated at 6 months after planting.

The estimates of broad-sense heritability (h^2) ranged from 0.27 for RL to 0.79 for SN (Table 3). According to the classification presented by Resende et al. (1995), these estimates ranged from medium to high (Table 3), with DMC and SN showing the highest estimates. In the study conducted by Diniz and Oliveira (2019), the authors found lower estimates for the same traits. Variables with high estimates indicate increased genetic variation for selection (PEPRAH et al., 2020). Heritability estimates help researchers define the most suitable selection strategies for each trait, the improvement methods, and the experimental design towards mitigating experimental errors and maximizing the genetic gain per selection (BORÉM; MIRANDA, 2013; OLIVEIRA et al., 2015).

The realized heritability ranged from 0.05 for PH to 0.91 for SN. These results reflect the significant effect of genotype x harvest interactions for the traits, as well as the actual genetic gains from selection. For variables with a significant interaction effect and high realized heritability, the interaction was likely simple; conversely, when these estimates are low, the type of interaction tends to be complex. The realized heritability of PH and RW, in general, was low. Therefore, these results suggest that early selection for these traits should be inefficient.

The estimates of the index of coincidence ranged from 100% to 25% for SW and RL, respectively (Table 3). These estimates evaluate the proportion of matching clones in both generations, reflecting the efficiency of early selection for the traits under study. In the present study, the estimates of SW, RD, DMC, and SD were generally high. According to Pedrozo et al. (2008), high values of the index of coincidence for a trait indicate high efficiency in the selection of superior genotypes for these traits.

The biplot (Figure 3) shows correlations between variables and genotypes, with principal component one (PC1) accounting for 29.4% total variation, whereas principal component two (PC2) accounted for 18.9% total variation. Yang et al. (2009) suggest that the first two principal components (PCs) should show at least 60% total variation. However, the scores of these components made it possible to differentiate the genotypes most correlated with the variables under study and to measure the degree of correlation between variables. Yang et al. (2009) highlight that such a value of minimum necessary total variation requires further research for confirmation.

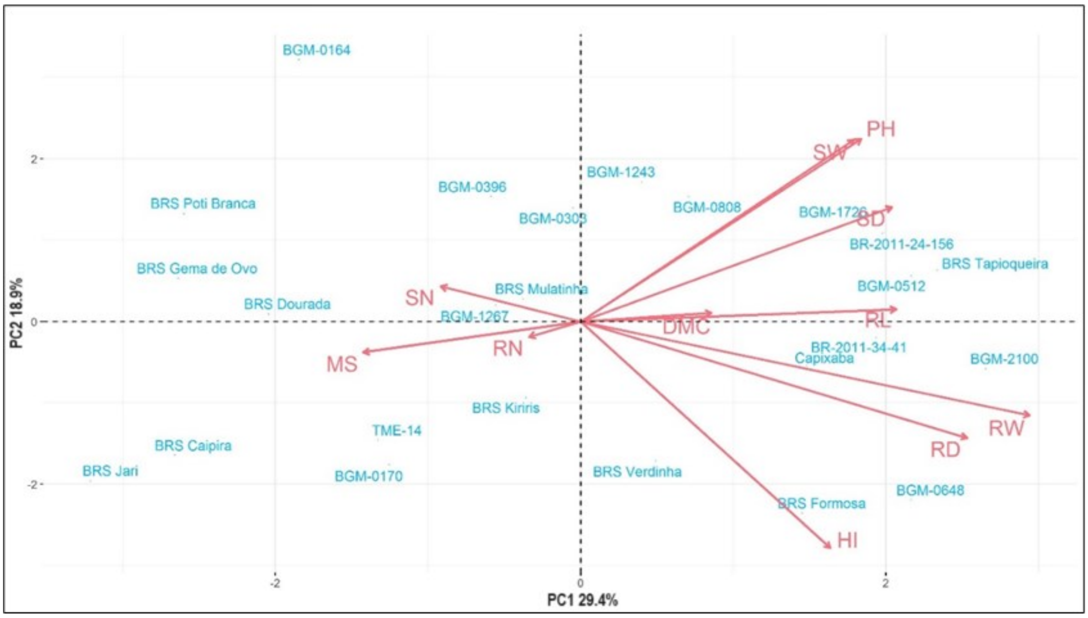

Figure 3. Genotype by Trait (GT) Biplot of the variables: RW – root weight (t ha^{-1}); SW - shoot weight (t ha^{-1}); PH - plant height in m; SD - stem diameter in mm; SN - stem number; MS - mite severity; RN - root number; RL - root length in cm; RD - root diameter in mm; DMC – root dry matter content of the 25 cassava genotypes.

The variables RW, RL, RD, HI, and DMC were highly correlated with the morphological traits PH and SD, and the variables SW, RN, SN, and MS were negatively correlated with the other traits under study (Figure 3). The variables RW, RL and RD were positively correlated. These results are somewhat expected because root weight depends on root width and length. A similar response was found by Njoku and Mbah (2020) when investigating inter-relations between fresh root yield and thirteen quantitative traits related to the yield of recently developed cassava genotypes in southeast Nigeria. Oliveira et al. (2021), when evaluating genetic parameters and the effects of different morphological traits on root yield by path analysis, observed a direct, positive effect of RD on RW and a positive correlation between these two variables. This result suggests that RW is a good predictor of the RD trait under water stress, enabling indirect selection for RD. For this reason, it may not be necessary to include the variable RD during the early drought genotype evaluation.

The results of correlations of the variables RW, RL, and RD with PH and SD suggest that the higher the value of these morphological variables is, the higher the root yield will be under water stress. Similar results were found by Diniz and Oliveira (2019), who observed a positive correlation between RW and PH. Conversely, the negative correlations between RN and PH, SW, SD, RL, RW, RD, DMC, and HI suggest that the increase in the mean of one of those characteristics may significantly reduce the mean RN (Figure 3). Data on the association between RW and the components RL and RD with PH and SD may help to predict the genotypes with the best yields, thereby increasing the efficiency of genetic improvement programs because root yield assessments in conventional genetic improvement programs are lengthy and costly, especially when conducting field tests (VITOR et al., 2019). The identification of characteristics predictive of yield enables indirect selection (DINIZ; OLIVEIRA, 2019).

The results of the negative correlation between the variables RN and RD corroborate the findings of Andrade et al. (2014), at 8, 10 and 12 months after planting. Conversely, the positive correlation assessed in the present study between RW and HI corroborates the findings of Peprah et al. (2020).

Similarly, negative correlation between RN and RL was also found by Paz et al. (2020) when studying the performance of five cultivars in the Cerrado.

PH was positively correlated with RL (Figure 3). Taller genotypes tend to show higher values of RL. Higher plant height estimates may be related to a marked development of the root system, capable of reaching high soil depths and, thus, more stably maintaining the photosynthetic rate under water stress conditions. A similar result was found by Mulualem and Ayenew (2012), in a research aimed at identifying cassava stages for improved yield.

MS was negatively correlated with RW, SW, and DMC. During feeding, mites cause damage, such as leaf chlorosis, total defoliation, stunted bud growth, root yield decrease to 80%, and low starch in storage roots. Therefore, a way to mitigate the effects of this pest is to use resistant cultivars (EZENWAKA et al., 2018).

In relation to the performance of the genotypes for the variables under study, Capixaba and BR-2011-34-41 were highly correlated with the variables DMC and RD. BGM-1726, BR-2011-24-156, BRS Tapioqueira and BGM-0512 were correlated with the variables PH, SD and SW. BRS Formosa stood out for the trait HI (Figure 3). The genotypes Capixaba and BR-2011-34-41 were positively correlated with the variable DMC. Diniz and Oliveira (2019) emphasize that genotypes with a high DMC have commercial production implications because genotypes with increased estimates make it possible to cut transportation costs per ton of starch.

The correlation results of BGM-1726, BR-2011-24-156, BRS Tapioqueira and BGM-0512 with the variables PH, SD and SW showed that genotypes combining these traits are crucial for the semi-arid region, especially for the Northeast region, because they are a desirable resource for animal feed, primarily during severe droughts, in addition to being greater sources of propagation material (OLIVEIRA et al., 2017).

BRS Formosa stood out for the trait HI (Figure 3). The high correlation of the commercial variety BRS Formosa with HI observed in the present study corroborates the findings of Oliveira et al. (2017), under water stress conditions. The authors observed that the BRS Formosa variety had the highest mean root yield and the best harvest index, also ranking among the varieties with the worst shoot yield. In studies adopting indices of selection for water stress, the variety has been classified as tolerant to water stress. Therefore, this variety may also be considered an alternative for cultivation under water stress conditions.

CONCLUSION

The genotypes showed matching results in the two harvests for most variables, except for stem number per plant, plant height, stem diameter, and harvest index. Root production was positively correlated with the other variables under study, with no positive correlation between above-ground stem number, root number, and mite severity. These results indicate that indirect selection for root weight is possible through variables positively correlated with the trait. The genotypes showed satisfactory root weights under water stress conditions. Early selection proved efficient for the traits shoot weight, root diameter, root dry matter content, and stem diameter because the indices of coincidence of these traits were higher than 50%.

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