Canonical correlations between traits of cassava plants propagated by an adaptation of rapid multiplication method[1]

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ABSTRACT

This study aimed to identify the correlations between traits of the groups stem cutting, seedling, stem, and root of cassava. Length, diameter, and weight of stem cutting (Group 1) were measured at each growing season (July, August, September, and October). A total of 300 cuttings were collected after sprouting and planted at seasons of September 22, October 7 and 19, and November 25. Plant height at planting, number of leaves at planting, and number of leaves at 7 days after planting were measured. The number of leaves at transplanting and plant height at transplanting were determined after acclimation (Group 2). Seedling transplanting was carried out on November 9 and 24 and December 3 and 26, and the traits stem (Group 3) and root (Group 4) yield were measured at harvest. Associations between the groups stem cutting and seedling were established by stem cutting diameter and weight, and height and number of leaves at planting. Seedling traits had the greatest influence on the number of buds per stem and stem diameter. Main stem branching height and stem diameter can be used for selecting plants with an indication of the best quality and yield of root traits.

Keywords: *Manihot esculenta* Crantz; plant propagation; multivariate analysis; relationship between traits.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is grown worldwide and plays an important role in increasing food security (Jarvis *et al.,* 2012). Brazil is the world's fourth largest producer of cassava (FAO, 2017) and approximately 87% of its production comes from family farms. Nevertheless, the mean yield on this type of property is 5,770 kg ha^{-1} (Brasil, 2009) and the low quality of the propagation material is one of the main causes of low yield (Silva *et al.,* 2013).

Improvement of management techniques is characterized as a low-cost and easy-to-implement alternative to increase the yield of food species, as the long cycle and the predominance of asexual propagation make it difficult to implement breeding programs for the cassava crop (Bredeson *et al.,* 2016). Qualitative and quantitative variations occur between growing years in the production of propagation material. The rapid multiplication method for cassava cultivation, developed by the International Center for Tropical Agriculture has the potential to increase the multiplication rate of high-quality propagation materials, especially during crops with restricted availability of stems.

Despite the existence of adaptations of this method for the Brazilian cultivation conditions (Santos *et al.,* 2009), there is little information on which stem cutting traits have the greatest influence on quality-seedling production, as well as which traits measured in seedlings contribute to higher stem and root yields. There are few reports on root

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yield at the first crop from the transplanting of seedlings produced by the rapid multiplication method. According to Santos *et al.* (2009), in the first year of cultivation with the use of seedlings produced by the rapid multiplication method occurs the production of small and uneven shaped roots.

Studies on the association between traits of agronomic interest are important. In this context, canonical correlation analysis is a multivariate statistical procedure that allows the study of the association of two groups of variables (Cruz & Regazzi, 1997). Despite the importance of studying linear relationships between traits in the quantification of intensity and the sense of correlation, knowledge of the linear association between groups allows the selection of morphological traits that have the greatest influence on the group of productive traits.

Thus, exploratory studies to identify associations between groups of traits in the cassava crop may assist in defining strategies for improving the rapid multiplication method for stem and root production. It is due to the possibility of identifying groups of traits that have a greater influence on the production of physiological quality seedlings with the potential to provide a higher yield of high-quality stems and roots. This study aimed to identify the correlations between traits of the groups stem cutting, seedling, stem, and root produced through an adaptation of the rapid multiplication method.

MATERIAL AND METHODS

A total of 600 two-bud stem cuttings of the cultivar Apronta Mesa were planted in 15-cell black plastic trays with dimensions of 34 cm long × 21 cm wide × 7.8 cm high during each season (July, August, September, and October 2017). Cells had 6.2 cm at the top × 5.0 cm at the bottom × 7.8 cm in height and five 6-mm holes in the base to drain excess water applied via irrigation. Trays were filled with the commercial substrate Mec Plant®. Stem cutting length (SCL), diameter (SCD), and weight (SCW) (Group 1) were measured at the stem cuttings, which were maintained in a Van der Hoeven agricultural greenhouse with a sprinkling irrigation system.

A total of 300 sprouted cuttings were collected at each growing season when they had at least three visible leaves. Leaf was considered visible when the edges of one of the leaf lobes did not touch each other (Schons *et al.,* 2007). After collection, cuttings were planted in 15-cells plastic trays filled with previously irrigated Mec Plant® commercial substrate to prevent tissue dehydration at planting. A one-centimeter deep furrow was opened, and one cutting was planted per cell. Planting was carried out in the morning, and the maximum allowed temperature was 25 °C to minimize the risk of dehydration of cuttings tissues. After planting at each season (September 22, October 7 and 19, and November 25), trays were placed in a Van der Hoeven greenhouse with an automatic mist irrigation system (6 mm day^{-1}) and mean temperature of 25 °C.

Plant height at planting (PHP) was measured from base to last visible leaf, and the number of leaves at planting (NLP) were counted. The number of visible leaves was counted again at 7 days after planting (NL 7 DAP). Seedlings were removed from the greenhouse at 30 DAP and taken to an agricultural greenhouse for a minimum of 5 days acclimation, except for growing season of November 25, when seedlings were acclimated at 23 DAP. The number of leaves at transplanting (NLT) and plant height at transplanting (PHT) (Group 2) were determined at each growing season, i.e., 48, 47, 44, and 31 DAP, respectively.

The preparation of the experimental area consisted of the desiccation of the winter crop formed by the intercropping of cover crops (*Avena strigosa* Schreb. + *Raphanus sativus* L.) with the herbicide glyphosate (1,440 g L^{-1}). The soil, classified as a clay textured typic dystrophic Red Latosol (Embrapa, 2013), was prepared conventionally, consisting of one plowing and one harrowing. A soil sample was taken from a depth of 0 to 20 cm to characterize soil fertility of the experimental area, showing the following values: pH in water = 5.5, clay = 50%, soil organic matter = 3.3%, phosphorus = 26.2 mg dm^{-3}, potassium = 96 mg dm^{-3}, calcium = 5.9 cmol$_c$ dm^{-3}, magnesium = 2.4 cmol$_c$ dm^{-3}, aluminum = 0.0 cmol$_c$ dm^{-3}, and base saturation = 68.7%.

Fertilization was based on the recommendations of the Comissão de Química e Fertilidade do Solo (2016) for the cassava crop. The mineral fertilizer formula 5–20–20 was applied at a dose of 334 kg ha^{-1} during transplanting. Nitrogen fertilization consisted of urea (46–00–00) split into two applications of 70 kg ha^{-1} at 15 days after transplanting (DAT) and beginning of starch accumulation (BSA), which occurs when cassava plants have 21 visible leaves on the main stem (Schons *et al.,* 2007).

The experimental area used in this study belongs to the University of Cruz Alta (Unicruz), Cruz Alta, Rio Grande do Sul, Brazil. Seedling transplanting was carried out according to each season on November 9 and 24 and December 3 and 26 in 15 cm deep unfertilized furrows and mean population of 18,681 plants ha^{-1}. Weed control was carried out weekly by manual weeding until the complete closure of interrows, which was extended up to three months after transplanting. Sprinkling irrigation was performed daily up to the 15th day after transplanting for all seasons when no precipitation was registered. Water supply is important for establishing cassava seedlings produced by the rapid multiplication method (Santos *et al.,* 2009).

Main stem branching height (MSBH), number of branches (NB), number of lateral shoots (NLS), number of buds per stem (NBS), stem length (SL), stem diameter (SD) (Group 3), root fresh matter (RFM), root length (RL), root diameter (RD), and number of roots (NR) (Group 4) were measured at harvest on May 30, 2018. Diameter measurements were performed using a digital caliper, with stem diameter represented by the mean of the basal, middle, and upper diameter, and root diameter measured in the upper third of roots. Root fresh matter was weighed on a precision scale with a resolution of 0.01 g. The measured traits formed the groups of canonical correlation variables. Plants were continuously numbered at each season to allow them to be assessed individually at the stages stem cutting (Group 1), seedling (Group 2), stem (Group 3), and root (Group 4).

The assumptions for the canonical correlation analysis were tested at each group of variables following the order multivariate normality, homoscedasticity of deviations, multicollinearity, and linearity. The multivariate normality was verified in the software R using the packages MASS and mvShapiroTest (Villasenor-Alva & Estrada, 2009). The homoscedasticity of deviations was verified by dispersion diagrams and plants that had standard deviation values higher than 4 or lower than −4 were considered discrepant and removed from the analysis (Hair *et al.,* 2009).

Multicollinearity was classified as established by Montgomery & Peck (1982) by condition number (CN) and variance inflation factor (VIF), being considered week when the condition number was lower than 100 and no exclusion of variables was needed. However, it was considered moderate to strong if the condition number presented values between 100 and 1000, and severe when this value was higher than 1000; in these cases, variables with a high degree of correlation were excluded. Values lower than 10 were accepted for the variance inflation factor, which served as an indication of the absence of multicollinearity, while values higher than 10 indicated variables that should be excluded (Kutner *et al.,* 2005).

Linearity was verified by the significance of the Pearson correlation coefficient at 0.05 error probability, in which variables that did not present at least one significant linear correlation with the other group were excluded. The canonical correlation analysis was performed between groups 1 and 2, 2 and 3, 2 and 4, and 3 and 4. The assumptions and the canonical correlation analysis were performed by the software Genes (Cruz, 2006), R (R Development Core Team, 2014), and Microsoft Excel.

RESULTS AND DISCUSSION

The linearity of the data was verified by Pearson linear correlation coefficients and traits were not excluded as they presented at least one significant linear relationship with traits from another group. The multivariate normality assumption within groups 1, 2, 3, and 4 was not met at the four growing seasons. Although normality is characterized as the most important assumption in multivariate analysis, its severity can be scaled by sample size when there is no normality. The absence of normality in small samples, i.e., data sets with the number of observations equal to or lower than 50, has the potential to substantially impact the results by invalidating the results of statistical tests. The effects of the absence of normality for large samples, as in more than 200 observations, may be suppressed or omitted and concern about the lack of normality in large sample sizes may be reduced (Hair *et al.,* 2009). In the present study, 239, 240, 240, and 226 observations were performed during the growing seasons of July, August, September, and October, respectively, for groups 1 and 2. On the other hand, 213, 231, 232, and 179 observations were performed during the growing seasons of stem cutting of August, September, and October, respectively, for groups 3 and 4.

Groups 1 and 3 showed no outliers, and only one value was observed in Group 2. After standardization of the deviations, the standard deviation value higher than 4 (outlier) was observed when stem cutting planting was performed in October for the trait plant height at planting (4.42), and the plant that presented it was removed from the analysis. Group 4 presented outliers at the growing seasons of July, August, and September, and 3, 2, and 1 plants were excluded from the analysis, respectively. The standardization of the deviations is recommended in the detection of outliers through dispersion diagrams since standardization facilitates the comparison between variables under study (Hair *et al.,* 2009).

The multicollinearity within groups of traits 1 and 2 at growing seasons of stem cuttings of July, August, and September had a condition number equal to or lower than 59.71, which indicated that multicollinearity was classified as weak, not requiring the exclusion of traits. The stem cutting planting performed in October presented a condition number of 167.11, and multicollinearity was characterized as moderate to strong for the group of traits measured in stem cuttings (Group 1). In this case, the trait stem cutting diameter, which presented a variance inflation factor of 12.93, was excluded. At this same growing season, the condition number was 282.03 for the group of traits measured in cassava seedlings (Group 2), and plant height at transplanting was excluded, which had a variance inflation factor of 16.79. The condition number showed values of 6.55 and 10.76 for Groups 1 and 2, respectively, after these traits were excluded.

Group 3 had a condition number higher than 412.50 at growing seasons of July, August, and September, and the trait stem length, which presented a variance inflation factor higher than 98.49, was excluded. The condition number presented values of 4.17, 3.09, and 6.53 for growing seasons of July, August, and September, respectively, after this trait was excluded. No exclusion of traits was needed for Group 4 since the condition number was equal to or lower than 40.85 at all growing seasons. Meeting the assumption of multicollinearity is important and has a stronger influence on the reliability of estimates than multivariate normality (Toebe & Cargnelutti Filho, 2013).

All growing seasons had at least the first canonical pair significant, with a linear dependence between Groups 1 and 2. The first coefficient is always higher than or equal to any simple correlation coefficient between traits of the first and second groups, and thus interpretation must be performed mainly by the first significant canonical pair (Cruz & Regazzi, 1997). In general, associations between groups of traits were established by stem cutting diameter and weight (Group 1), as well as by plant height at planting and number of leaves at planting (Group 2). The other traits showed less influence and contribution to the explanation of the correlation between groups.

Stem cutting planting carried out in July presented the first canonical pair with a correlation coefficient of 0.4444 (Table 1). Higher weight and smaller diameter stem cuttings provided higher plant height at planting. It is an indication that the planting of intermediate diameter (± 20 mm) stem cuttings in this month can be prioritized from the agronomic point of view to obtain cuttings with better initial growth capacity and larger number of leaves at transplanting. Considering that cassava planting is not recommended in Rio Grande do Sul in July, possibly the planting of larger (close to 25 mm) and smaller diameter (close to 15 mm) stem cuttings may reduce the initial growth capacity of sprouts, mainly influenced by lower temperatures. Stem cuttings with a lower amount of reserve substances limit the development of sprouts under adverse climate conditions (Cardoso *et al.,* 2004).

Planting carried out in August presented the first canonical pair with a coefficient of 0.4844. Larger diameter stem cuttings provided the highest plant height at planting. The increased mean air temperature in August favored the growth of cuttings from larger diameter stem cuttings and positively influenced plant height at planting due to the higher amount of reserves available. The other traits presented low magnitude coefficients and did not contribute to the interpretation of the canonical correlation between groups at this growing season.

Stem cutting planting of September had the first two canonical pairs significant, with coefficients of 0.6344 and 0.2459, respectively. Cuttings from higher weight and diameter stem cuttings had higher plant height at planting and lower number of leaves at planting, i.e., growth and lower initial development were favored. Stem cuttings of larger diameter and shorter length, and, consequently, lower weight, provided cuttings with a lower number of leaves at planting. However, the number of leaves at transplanting was favored, indicating that despite the slow initial development, the initial nutritional support provided by larger diameter stem cuttings favored the development and production of cassava seedlings with a higher number of leaves at transplanting. According to Mattos & Cardoso (2003), the planting of 25-mm diameter stem cuttings should be prioritized in the traditional planting method.

Growing season carried out in October showed a coefficient of the first canonical pair of 0.3316. The higher stem cutting weight provided cuttings with higher plant height, lower number of leaves at planting, and a higher number of leaves at 7 days after planting. It indicated that the higher stem cutting weight led to a reduced leaf fall and higher rooting and emission of new leaves after the planting of cuttings. Higher plant height at planting indicated the highest vigor of cuttings, and hence endogenous factors favored adventitious rooting and leaf emission after planting (Hartmann *et al.,* 2002). An increase in the storage time of stems led to the natural reduction of water content and reserves due to stem sprouting in the storage place. Thus, higher weight stem cuttings were important to obtain vigorous cuttings, especially when planting was carried out in a late growing season that required longer storage time of the propagation material.

Table 1: Coefficients of canonical pairs for traits of Groups 1 and 2 with stem cutting planting carried out in July, August, September, and October

July				**August**			
	Coefficients of canonical pairs				Coefficients of canonical pairs		
Traits	1º	2º	3º	Traits	1º	2º	3º
Group 1				Group 1			
SCL[1]	-0.2222	0.1444	1.4051	SCL	0.4758	0.6176	1.3065
SCD	-0.7816	1.9226	1.4185	SCD	0.8642	2.0663	0.5731
SCW	1.6706	-1.3612	-1.4938	SCW	0.0368	-2.2456	-1.1741
Group 2				Group 2			
NLP	-0.1870	-0.0244	-0.0517	NLP	-0.1763	0.3337	1.1005
NL 7 DAP	-0.2736	0.4588	-0.9256	NL 7 DAP	-0.2385	-1.1266	-0.0049
PHP	1.0986	-0.5630	0.1032	PHP	1.0858	-0.1988	-0.1823
PHT	-0.1835	0.1998	-0.8495	PHT	-0.0338	-0.3088	-0.1425
NLT	0.4141	0.6916	1.0781	NLT	0.1029	1.1879	0.0265
Canonical correlation (r)	0.4444^{*}	0.1413^{ns}	0.0561^{ns}	Canonical correlation (r)	0.4844^{*}	0.1539^{ns}	0.1407^{ns}
Significance (X^2)	< 0.01	0.71	0.86	Significance (X^2)	< 0.01	0.24	0.20
Degrees of freedom	15	8	3	Degrees of freedom	15	8	3

September				**October**		
	Coefficients of canonical pairs				Coefficients of canonical pairs	
Traits	1º	2º	3º	Traits	1º	2º
Group 1				Group 1		
SCL	-0.0326	-0.6505	1.5648	SCL	0.3209	1.0423
SCD	0.4287	0.7590	2.4291	SCW	0.8277	-0.7101
SCW	0.6293	-0.5858	-2.7451	Group 2		
Group 2				NLP	-0.8833	-1.6245
NLP	-0.6968	-0.9669	0.1756	NL 7 DAP	0.7842	1.7262
NL 7 DAP	0.1701	0.2100	0.1734	PHP	1.0958	-0.2572
PHP	1.0362	-0.3454	0.2321	NLT	-0.4790	0.1783
PHT	0.1041	0.1677	-1.2701	Canonical correlation (r)	0.3316^{*}	0.1380^{ns}
NLT	0.2567	0.7395	0.8973	Significance (X^2)	< 0.01	0.24
Canonical correlation (r)	0.6344^{*}	0.2459^{*}	0.1174^{ns}	Degrees of freedom	8	3
Significance (X^2)	< 0.01	< 0.05	0.35			
Degrees of freedom	15	8	3			

*Significant by the chi-square test at 0.05 probability ($P < 0.05$).
[1]SCL (stem cutting length); SCD (stem cutting diameter); SCW (stem cutting weight); NLP (number of leaves at planting); NL 7 DAP (number of leaves at 7 days after planting); PHP (plant height at planting); PHT (plant height at transplanting); NLT (number of leaves at transplanting).

In general, during the growing seasons, among the traits of Group 1, stem cutting weight and diameter had the strongest influence and contribution to explain the linear dependence between Groups 1 and 2. On the other hand, stem cutting length showed low coefficients and contributed little to explain the linear dependence between groups. Thus, stem cutting weight and diameter might be considered to select propagation material in this multiplication method.

Stem cutting planting carried out in July presented the first two canonical pairs significant in the correlations between Groups 2 and 3 (0.5622 and 0.4217) and 3 and 4 (0.8314 and 0.3097). Also, only the first canonical pair was significant in the correlation between Groups 2 and 4 (0.3070) (Table 2). At this time of seedling transplanting, the higher the plant height at transplanting and the lower the number of leaves at transplanting are, the lower the main stem branching height and stem diameter. The higher seedling growth led to stress after transplanting caused by the increased transpiration and higher energy expenditure to maintain the basic physiological functions for its survival, which resulted in a negative effect on the main stem branching height and especially on stem diameter. The highest plant height at planting and lowest number of leaves at planting of stem cuttings had a positive influence on root length between Groups 2 and 4. In addition, the maintenance of leaves after the planting of cuttings for seedling production in July, i.e., a higher number of leaves at 7 days after planting, was important to obtain seedlings with higher physiological quality and ability to produce longer roots.

Table 2: Coefficients of canonical pairs for traits of Groups 2, 3, and 4 with stem cutting planting carried out in July, August, and September (Continue...)

	July			**August**			**September**		
	Coefficients of canonical pairs								
Traits	1º	2º	3º	1º	2º	3º	1º	2º	3º
Group 2									
NLP[1]	0.3673	0.0318	1.1499	0.8250	0.8886	-0.4666	-0.2889	-0.8995	1.2056
NL 7 DAP	-0.4766	0.5126	0.2292	-0.1035	-0.0074	1.2570	-0.0330	0.1568	-0.6756
PHP	-0.4238	0.5563	-0.9087	-0.0173	-0.6136	0.4007	0.5421	0.9518	0.4577
PHT	0.9743	0.1969	-0.0695	0.6228	-0.5874	-0.1692	0.6243	-0.7863	-0.5119
NLT	-0.0647	0.0217	-0.1987	-0.8747	0.3480	-0.6877	0.2570	0.3927	-0.1170
Group 3									
MSBH	-0.8015	-0.5531	0.5582	-0.0398	-0.3349	-0.4170	0.1788	1.0901	0.1021
NLS	-0.2695	0.8587	0.4759	0.0550	-0.6357	0.3475	0.1692	0.0126	0.2829
NB	0.0581	-0.2236	0.5088	-0.6564	0.3375	-0.5016	-0.0576	0.2793	-0.2780
NBS	0.463	0.2485	0.1132	0.7230	0.1355	-0.6311	0.5184	-0.6803	-1.1829
SD	-1.0474	-0.0348	-0.4843	0.3591	0.5493	0.6167	0.4958	0.1989	1.1796
Canonical correlation (r)	0.5622*	0.4217*	0.2116ns	0.2681*	0.2257ns	0.1825ns	0.5997*	0.3709*	0.1338ns
Significance (X^2)	< 0.01	< 0.01	0.34	0.02	0.07	0.16	< 0.01	< 0.01	0.78
Degrees of freedom	25	16	9	25	16	9	25	16	9

Continue...

Table 2: Coefficients of canonical pairs for traits of Groups 2, 3, and 4 with stem cutting planting carried out in July, August, and September (Continuation...)

	July			August			September		
	Coefficients of canonical pairs								
Traits	1º	2º	3º	1º	2º	3º	1º	2º	3º
Group 2									
NLP	-0.4268	-0.3569	0.4065	0.2886	-1.0246	-0.4481	0.2619	-1.2793	-0.9688
NL 7 DAP	0.8885	0.0456	-0.7740	-0.2386	-0.0119	0.9972	-0.0069	0.7857	0.7086
PHP	0.5667	-0.6027	0.5119	1.0500	0.4286	0.0056	-0.0490	0.9453	-0.6635
PHT	-0.4805	-0.0212	-0.4363	-0.3227	0.3326	0.8646	0.9500	0.0191	0.3906
NLT	-0.0386	0.8828	0.9633	-0.1672	-0.2911	-0.4815	-0.1162	-0.1964	0.2853
Group 4									
RFM	0.0292	1.5130	1.2059	-0.0893	2.3362	1.3576	0.5242	2.0366	0.3079
RL	0.9356	-0.6697	-1.0342	1.2249	-0.9148	-0.6956	0.1261	-0.0033	0.4772
RD	-0.1318	0.2306	-0.0421	-0.8350	-1.0171	0.0886	-0.2840	-1.6874	0.3900
NR	0.3652	-1.4334	0.0637	0.4025	-2.1266	-0.2143	0.6220	-1.4440	-0.4633
Canonical correlation (r)	0.3070^{*}	0.2545^{ns}	0.1708^{ns}	0.2309^{ns}	0.1820^{ns}	0.1234^{ns}	0.3642^{*}	0.1870^{ns}	0.1651^{ns}
Significance (X^2)	< 0.01	0.06	0.39	0.25	0.49	0.70	< 0.01	0.18	0.23
Degrees of freedom	20	12	6	20	12	6	20	12	6

	July			August			September		
	Coefficients of canonical pairs								
Traits	1º	2º	3º	1º	2º	3º	1º	2º	3º
Group 3									
MSBH	-0.4842	0.0007	1.0577	-0.4863	0.5390	0.6069	-0.6696	0.2718	0.8406
NLS	0.4677	-0.6644	0.2027	0.3964	0.4572	-0.2380	0.2613	-0.0650	0.5859
NB	0.0514	-0.5382	-0.1448	-0.0176	-0.6082	0.1060	0.0066	-0.2327	-0.2798
NBS	0.2008	-0.6709	-0.4368	0.0498	-0.5816	0.5362	0.0774	-1.3653	-0.3405
SD	0.6694	0.4938	0.7861	0.6804	0.4615	0.3262	0.6843	0.8587	0.5997
Group 4									
RFM	-0.1663	1.6906	-0.5868	0.2633	2.6162	-0.6982	0.1063	1.6095	2.4575
RL	0.4979	-0.4563	1.2893	0.1912	-1.1491	1.1410	0.2781	-0.9077	-0.7008
RD	0.3599	-0.0639	-0.5722	0.4118	-0.7983	0.1542	0.3365	0.1946	-1.5904
NR	0.7570	-1.5762	0.0585	0.5858	-2.0929	0.0118	0.6973	-1.4943	-1.2525
Canonical correlation (r)	0.8314^{*}	0.3097^{*}	0.1812^{ns}	0.8598^{*}	0.3560^{*}	0.1785^{ns}	0.8664^{*}	0.2468^{ns}	0.1438^{ns}
Significance (X^2)	< 0.01	< 0.01	0.10	< 0.01	< 0.01	0.13	< 0.01	0.08	0.52
Degrees of freedom	20	12	6	20	12	6	20	12	6

*Significant by the chi-square test at 0.05 probability ($P < 0.05$).
[1]NLP (number of leaves at planting); NL 7 DAP (number of leaves at 7 days after planting); PHP (plant height at planting); PHT (plant height at transplanting); NLT (number of leaves at transplanting); MSBH (main stem branching height); NLS (number of lateral shoots); NB (number of branches); NBS (number of buds per stem); SD (stem diameter); RFM (root fresh matter); RL (root length); RD (root diameter); NR (number of roots).

Between Groups 3 and 4, the lower the main stem branching height and the larger the stem diameter were, the higher the number, length, and diameter of roots for stem cutting planting carried out in July. Larger stem diameter allowed the largest supply of reserves, being translocated to the root system and favoring its growth and development. The lower main stem branching height contributed to the early development of secondary branches and thus to leaf emission, increasing the leaf area responsible for the interception of solar radiation and production of photoassimilates directed and accumulated in roots (Tironi *et al.,* 2015). Leaf area is important for photochemical reaction and atmospheric carbon fixation, which has a direct action on plant growth and development and dry matter accumulation (Phothi & Theerakarunwong, 2017). According to Alves (2006), the total leaf area is dependent on the branching pattern, the number of leaves per stem, and its size and longevity.

Stem cutting planting carried out in August had the first canonical pair significant between Groups 2 and 3 (0.2681) and the first two pairs canonical significant between Groups 3 and 4 (0.8598 and 0.3560), with no canonical pairs between Groups 2 and 4 (Table 2). The higher the number of leaves at planting and the lower the number of leaves at transplanting were between Groups 2 and 3, the higher the number of buds per stem and stem diameter. It showed that the planting of cuttings with the highest number of leaves at this season is crucial to obtain vigorous seedlings and that the lower number of leaves in seedlings at transplanting was important to increase stem yield traits (number of buds per stem and stem diameter). The main initial photoassimilate flow is directed to stems, where accumulation occurs, being later directed to the storage roots (Alves, 2006).

Between Groups 3 and 4, plants with lower main stem branching height and larger stem diameter had a positive effect on root yield traits, mainly the number and diameter of roots, similar to that observed at the growing season of July. The accumulation of shoot dry matter in stems and leaves acted as a source of photoassimilates, and the accumulation in storage organs is mainly dependent on the number and mass of roots (Alves, 2006). The second canonical pair showed that plants with a higher main stem branching height presented a lower number, length, and diameter of roots. Plants with excessive height and, consequently, a higher main stem branching height, have a higher photoassimilate consumption for the formation of the photosynthetic apparatus, as well as a high-energy cost with respiration, contributing to reduce yield (Floss, 2011). Therefore, the main stem branching height of the cultivar Apronta Mesa may be used as a trait to select plants with better quality root production when produced by the adaptation of the rapid multiplication method.

Stem cutting planting in September was significant for the first two canonical pairs between Groups 2 and 3 (0.5997 and 0.3709) and only the first pair for Groups 2 and 4 (0.3642) and 3 and 4 (0.8664) (Table 2). Also, seedlings with higher plant height at planting and transplanting provided plants with a higher number of buds per stem and stem diameter. According to the second canonical pair, cuttings with a lower number of leaves and higher plant height at planting resulted in seedlings of lower plant height at transplanting and provided plants with higher main stem branching height and lower number of buds per stem. This result is not interesting considering the importance of quality stem yield, especially in crops with a shortage of propagation material. Cassava cultivation for stem production has grown in importance in recent years, being an alternative for diversifying and increasing the income of farmers (Edet *et al.,* 2015).

Seedlings with higher plant height at transplanting (Group 2) originated plants with a higher number of roots and root fresh matter (Group 4), indicating that seedling growth until the acclimation period was important and had a beneficial effect on root yield at the first growing season. During growth, photosynthesis products should be distributed for the emission of new leaves and stems to build the photosynthetic apparatus, being later directed to root drains (Alves, 2006). The use of seedlings with high physiological and sanitary quality was one of the main factors for the successful use of the adaptation of the rapid multiplication method.

Between Groups 3 and 4, plants with lower main stem branching height and larger stem diameter presented better results in traits measured in the storage roots, especially the number, diameter, and length of roots. This result observed in the growing seasons of July, August, and September may be related to genetic and management factors, such as the proximity of the date of seedling transplanting, especially regarding environmental conditions. Synthesis of photosynthesis products is important and dependent on shoot growth and development. The establishment of the shoot leads to an increase in the net photosynthesis rate and hence, a significant increase in root diameter as photoassimilates are directed to root drains (Figueiredo *et al.,* 2014). The balance in the development of the shoot and the root system and its relationship of source and drain are important to obtain high yields in the cassava crop (Alves, 2006).

Stem cutting planting carried out in October presented the first two canonical pairs significant between Groups 2 and 3 (0.5099 and 0.3040) and 3 and 4 (0.8599 and 0.3127), while between Groups 2 and 4, only the first pair was significant (0.3586) (Table 3). Also, between Groups 2 and 3, the highest plant height at planting of cuttings and the highest number of leaves at 7 days after planting provided plants with larger stem diameter and lower number of buds per stem. On the other hand, the second canonical pair showed that that the highest number of leaves at planting followed by the lowest number of leaves at 7 days after the planting, which was caused by the fall of basal leaves from seedlings of smaller height at planting and, consequently, lower height at transplanting, resulted in plants with lower number of buds per stem, which clearly reflected the result of lower seedling vigor.

Between Groups 2 and 4, cuttings with a lower number of leaves and plant height at planting, but which maintained or emitted new leaves soon after planting and showed higher growth until transplanting (PHT), resulted in plants with larger root diameter. As it is a late growing season and even out of the agricultural zoning, this information is especially important when prioritizing the production and selection of roots for marketing in the first year of cultivation in the late seedling transplanting. Moreover, the diameter is an important trait for the definition of marketable roots.

Between Groups 3 and 4, plants with larger stem diameter and lower main stem branching height provided the highest number of roots and root fresh matter. It shows that cassava has high adaptability to different cultivation conditions and plants prioritized the storage of carbohydrates and soluble solids in stem tissues for translocation in the period of starch accumulation in the roots even with seedling transplanting on December 26. Nevertheless, the coefficients found for root diameter and length were low, indicating that seedling transplanting carried out in the third ten-day period of December reduced the commercial quality of the produced roots. Fagundes *et al.* (2010) verified a gradual reduction of shoot growth and development with a delay of the growing season, resulting in a decreased leaf emission, synthesis of photoassimilates, and dry matter accumulation in stems and roots.

However, cassava cultivation at late seedling transplanting seasons may be an alternative of offering shoot and roots for animal feed or, mainly, harvesting of roots in the following off-season. In this case, pruning should be performed in May, coinciding with the beginning of the vegetative dormancy period caused by the temperature reduction in southern Brazil. According to Aguiar *et al.* (2011), pruning in the vegetative dormancy period does not change root yield and its anticipation to the end of the first crop cycle or after the beginning of the second cycle negatively affects root yield.

The cassava crop can remain at vegetative dormancy in case of biotic or abiotic stresses, returning to normal physiological conditions under appropriate conditions, which is an adaptation to different environmental conditions (Ceballos *et al.,* 2011). In early spring, as temperature increases and metabolic functions resume, plants leave the vegetative dormancy and start a period of intense sprouting, leaf emission, and construction of the photosynthetic apparatus. Consequently, there is an increase in starch accumulation in the roots, which can be harvested in November and December, a period that coincides with the seasonal period of low availability of fresh cassava roots for commercialization.

Table 3: Coefficients of canonical pairs for traits of Groups 2, 3, and 4 with stem cutting planting carried out in October

	October		
	Coefficients of canonical pairs		
Traits	1º	2º	3º
Group 2			
NLP[1]	-0.4229	2.1411	-0.0885
NL 7 DAP	0.6745	-1.2782	1.2154
PHP	0.5847	-0.4938	-0.8268
PHT	0.3484	-0.5102	-0.2596
NLT	0.1050	0.2542	-0.1063
Group 3			
MSBH	-0.1544	0.4997	-1.1924
NB	0.0183	0.0520	-0.0738
NBS	-0.6988	-0.9802	0.5375
SL	-0.0105	0.7978	0.7805
SD	0.9108	0.2893	-0.1285
Canonical correlation (r)	0.5099*	0.3040*	0.1975ns
Significance (X^2)	< 0.01	< 0.05	0.30
Degrees of freedom	25	16	9

	October				**October**		
	Coefficients of canonical pairs				Coefficients of canonical pairs		
Traits	1º	2º	3º	Traits	1º	2º	3º
Group 2				Group 3			
NLP	-0.6832	-0.7793	1.4623	MSBH	-0.3203	0.3138	0.5570
NL 7 DAP	0.8048	1.4489	-0.8320	NB	0.0471	-1.0766	0.1142
PHP	-0.4047	0.4303	-0.0776	NBS	0.3219	-0.0249	-0.5375
PHT	0.9663	-0.1735	-0.2717	SL	0.0945	-0.0471	-0.9413
NLT	0.0514	-0.4552	0.5627	SD	0.8123	0.6905	0.1981
Group 4				Group 4			
RFM	0.2648	1.1190	-1.2183	RFM	0.5267	1.6157	2.2417
RL	-0.2922	0.6742	0.9781	RL	0.1397	0.0578	-1.4607
RD	0.9251	-0.7127	-0.2765	RD	0.1041	-1.4128	0.1182
NR	0.2644	-1.0800	1.5899	NR	0.4302	-1.1831	-1.7344
Canonical correlation (r)	0.3586*	0.2463ns	0.1611ns		0.8599*	0.3127*	0.1509ns
Significance (X^2)	< 0.01	0.20	0.56		< 0.01	< 0.05	0.60
Degrees of freedom	20	12	6		20	12	6

*Significant by the chi-square test at 0.05 probability ($P < 0.05$).
[1]NLP (number of leaves at planting); NL 7 DAP (number of leaves at 7 days after planting); PHP (plant height at planting); PHT (plant height at transplanting); NLT (number of leaves at transplanting); MSBH (main stem branching height); NB (number of branches); NBS (number of buds per stem); SL (stem length); SD (stem diameter); RFM (root fresh matter); RL (root length); RD (root diameter); NR (number of roots).

CONCLUSIONS

Associations between the groups stem cutting and seedling were established by stem cutting diameter and weight, and plant height and number of leaves at planting.

Traits measured in seedlings had the strongest influence on the number of buds per stem and stem diameter.

Growth traits measured on seedlings in stem cutting plantings carried out in July, September, and October growth had a positive effect on root yield traits.

Main stem branching height and stem diameter can be used for selecting cassava plants with an indication of the best quality and yield of root traits.

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