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Preharvest management and harvest times of sweet cassava

Manejo pré-colheita e épocas de colheita de mandioca de mesa

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Studies on postharvest handling and pruning practices of cassava grown for consumption consist of varying, often inconsistent, information, thereby being necessary to broaden the available knowledge. Therefore, this work aims to evaluate the management of the aerial part and harvesting times of table cassava in the municipality of Vitória da Conquista, BA. The randomized block design was used, with treatments arranged in a split plot design. Managements (pruning and defoliation) as well as the control were assigned to plots, and two harvest times (8 and 12 months) were assigned to subplots, with 4 replicates. At 212 and 334 days after planting, pruning and defoliation of shoots were carried out; 30 days later, roots were harvested. The 12-month-long cycle was associated with the highest yield (13.18 t ha^{-1}) and better root conservation (6.98%); however, roots showed higher quality for consumption when harvested earlier (8 months). Pruning 30 days before harvest is a practice that reduces physiological spoilage of roots when compared to plants without shoot management.
Keywords: *Manihot esculenta* Crantz, root conservation, technological quality.

Estudos sobre manejo pós-colheita e práticas de poda em mandioca cultivada para consumo consistem em informações variadas, muitas vezes inconsistentes, sendo necessário ampliar o conhecimento disponível. Portanto, este trabalho tem como objetivo avaliar o manejo da parte aérea e épocas de colheita de mandioca de mesa no município de Vitória da Conquista, BA. Foi utilizado o delineamento em blocos casualizados com os tratamentos arranjados em esquema de parcelas subdivididas. Os manejos (poda e desfolha) foram distribuídos nas parcelas e duas épocas de colheita (8 e 12 meses) em subparcelas, com 4 repetições. Aos 212 e 334 dias após o plantio, foram realizadas podas e desfolha da parte aérea, e 30 dias depois, as raízes foram colhidas. O ciclo de 12 meses foi associado à maior produtividade (13,18 t ha^{-1}) e melhor conservação das raízes (6,98%); no entanto, as raízes apresentaram maior qualidade para consumo in natura quando colhidas mais cedo (8 meses). A poda 30 dias antes da colheita é uma prática que reduz a deterioração fisiológica das raízes quando comparada a plantas sem manejo da parte aérea.
Palavras-chave: *Manihot esculenta* Crantz, conservação das raízes, qualidade tecnológica.

1. INTRODUCTION

In tropical and subtropical countries, the predominant cropping system of cassava roots is characterized by low root yields (8 to 12 t ha^{-1}), while the world average reaches 25-30 t ha^{-1}. In Northeast Brazil, cassava (*Manihot esculenta* Crantz) is mainly grown by family farmers, with average yields of 9,50 t ha^{-1} [1]. However, constraints to full expression of the production capacity of this species are related to cultivation in marginal areas, inadequate management practices and low potential for implementing effective accesses to the production system [2].

Improving liquidity through shorter production cycles or early maturing, and higher product value can be achieved by cultivation of sweet cassava, thus being a special product. One of the facts that restricts commercialization of cassava roots is the short postharvest conservation time (two or three days after harvest) [2], due to factors mainly related to postharvest physiological deterioration (PPD).

Due to the multigenic nature of favorable traits, the incorporation of these traits without causing alterations to the pre-established characteristics of interest presents a major challenge. [3]. The attributes that improve cultivation, production, and quality of roots are inversely correlated to the postharvest conservation potential, limiting the role of plant breeding in the short term.

Research suggests some pre harvest and postharvest management methods have been proposed to systematize strategies aimed to reduce PPD. Postharvest operations such as the control of temperature and humidity in storage places, enzymatic inactivation, application of chemical compounds and use of cling film to protect the roots' surface can reduce losses from injuries that occur during the postharvest period [4].

Pre-harvest management techniques, such as agricultural practices that modulate the relationship between the aerial part of the plant and root volume, harvest times and pruning are the main strategies adopted in field cultivation, affecting not only production, but also the culinary quality of sweet cassava roots [5].

Restriction of the vegetative vigor of the leaf canopy is a phenomenon that is naturally associated with harvest time and can be induced by pruning. Drastic pruning, with total or partial removal of the plant leaf canopy or only a partial or total defoliation are agricultural practices associated with reduced shoot vigor. This practice induces an increase of the sugars/starch ratio in the roots, limited accumulation of scopoletin, and increased activation of the enzyme phenylalanine ammonia-lyase, delaying the PPD of roots [6]. Pruning-harvest intervals between seven [7] and 42 days [6] have been reported and associated with a positive impact on cooking quality, reduced PPD, and no interference in the productive characteristics of sweet cassava roots.

The diversity of effects in studies addressing the relationship between harvest times and pruning practices must be interpreted based on this discernment because they involve different management practices and abiotic and biotic factors. Due to the multifactorial interaction of these practices determined by the abiotic factors of the crop sites and variation of pruning treatments and times, a systematization of the knowledge of these practices becomes necessary.

Therefore, this study aims to evaluate the management of the aerial part and its effect on culinary quality, post-harvest conservation and root productivity at harvest times in the municipality of Vitória da Conquista, Bahia.

2. MATERIAL AND METHODS

2.1 Experiment period and location

The work was conducted at the property Campo Verde located in the Capinal village, rural area of Vitória da Conquista, BA, in the period of December 2017 to December 2018. The property is located at coordinates 15°01'57" S and 40°74'93" W, 928 m of altitude. The climate according to Koppen clasification is Cwa (subtropical humid). The meteorological data relating to rainfall (mm), relative air humidity (RH %), maximum and minimum temperature (°C) recorded during the field experiment are shown in Figure 1.

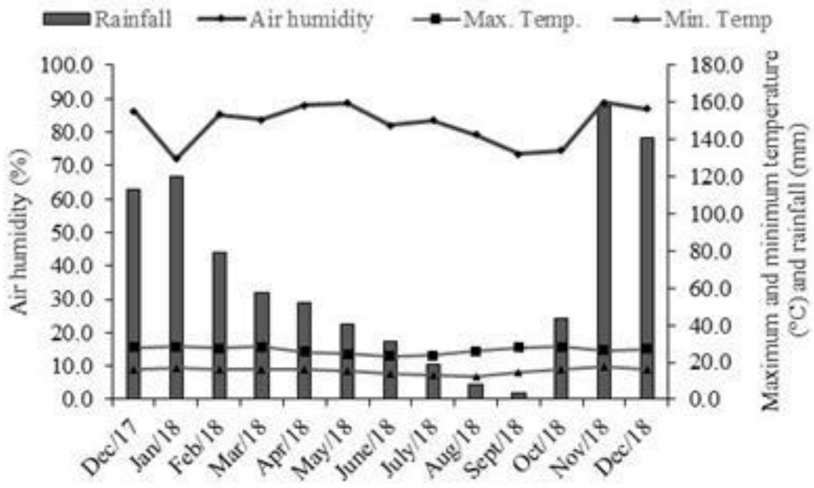

Figure 1: Monthly averages of precipitation, relative air humidity, maximum and minimum temperature in Vitória da Conquista, BA, from December 2017 to December 2018. Source: National Institute of Meteorology - INMET/Vitória da Conquista, Bahia state (2019).

The soil in the experimental area was classified as Yellow Dystrophic Latosol with sandy clay texture and a flat relief. The chemical analysis of the soil was carried out at the soils laboratory at the Universidade Estadual do Sudoeste da Bahia (UESB), and had the following results: pH (in water) = 5.1; P = 2.0 mg dm^{-3} (Mehlich Extractor); K^+ = 0.05 $cmol_c$ dm^{-3} (Mehlich Extractor); Ca^{2+} = 2.2 $cmol_c$ dm^{-3} (KCl 1 M Extractor); Mg^{2+} = 1.8 $cmol_c$ dm^{-3}(KCl 1 M Extractor); Al^{3+} = 1.3 $cmol_c$ dm^{-3} (KCl1 M Extractor); H^+= 10.8 $cmol_c$ dm^{-3}($CaCl_2$ 0.01, and SMP); Total exchangeable bases = 4.0 $cmol_c$ dm^{-3}; Effective Cation Exchange Capacity (CEC) = 5.3 $cmol_c$ dm^{-3}; CEC at pH 7.0 = 16.1 $cmol_c$ dm^{-3}; Base saturation = 25.0%; Aluminum saturation = 24.0%; Organic matter = 64 g dm^{-3}.

2.2 Experimental design

The experimental design consisted of randomized blocks with split plots, with pruning and defoliation of the plant shoots (pruning at the height of 15 cm above the ground and defoliation by removing all young, and mature leaves, petioles and new shoots from the aerial part of the plant, but maintaining the main stem), as well as one control treatment assigned to the plots, and two harvest times (8 and 12 months after planting) to the subplots, with four replicates. Pruning and defoliation were carried out 30 days before harvest following studies that adopted preharvest pruning to conserve cassava roots [6].

The plot consisted of an area of 78 m^2, comprised of three rows (26 m x 1.0 m), and the net area of each subplot consisted of a central row (12 m x 1.0 m), with a total of twelve cassava plants. Spacing was 1.0 m between rows and 1.0 between plants.

2.3 Installation and conduct of the experiment

The soil was tilled according to local cultivation practices, using plowing and harrowing, and the furrows were opened at a depth of 10 cm without fertilization and liming.

Fertilization and liming were not carried out in the experiment to simulate the typical environment of the crops cultivated in the region, where these practices have not yet to be widely used by most cassava growers.

For planting, stem cuttings of cassava cv. Milagrosa were selected, a variety largely cultivated in the study region and sold in street markets in the town, with good acceptance by consumers.

Planting was made manually in December 2017, using healthy cuttings, 20 cm long and two to three cm in diameter, with an average number of seven buds, laid horizontally in the furrows. Weed control consisted of two weed removals using a hoe five and ten months after planting.

2.4 Harvest and post-harvest evaluation of tuberous roots

At 212 and 334 days after planting, preharvest pruning of the shoots and defoliation of the cassava plants were carried out. At 30 days after pruning, the plants 8 to 12 months of age were harvested on each subplot using a hoe to pull out the roots. After harvesting, the cassava roots were taken to the Laboratory of Plant Breeding and Production at UESB for the following analyses: a) Total yield of the tuberous roots, which was determined by weighing all roots; b) Average root length, measured in ten selected roots with the same size from one end to the other, shortly after harvesting, using a graduated measuring tape; c) Average root weight, by weighing after harvesting ten roots from each subplot; d) Root dry matter, determined by the hydrostatic weighing method, based on the following formula: $DM = 15.75 + 0.0564\ R$, where R is the weight of 3kg of roots in water [8]; e) Starch content in tuberous roots, calculated by subtracting the dry weight by the constant 4.65 [9]; f) Peeling efficiency of cassava roots, which was classified into three categories: easy peeling, moderate peeling, difficult peeling); g) Cooking time and classification of boiled mass (pulp) [10]; h) Hardness, measured in root samples using a TR texture meter (model WA68, Italy), with two readings carried out on the equatorial regions of both sides of the same root; i) Amylose and amylopectin contents, which were determined based on [11]; and j) Moisture content, determined by the gravimetric method.

The assay to determine PPD of roots was carried out at the Laboratory of Plant Breeding and Production of UESB in ambient conditions, following a completely randomized design with six treatments and three replicates, totaling 18 plots. The treatments were arranged in a 3x2 factorial design, consisting of three types of management and two harvest times.

PPD of cassava roots was determined following the method proposed by [12]: three roots were selected from each treatment, with an average length of 18 cm, without mechanical damage and postharvest deterioration.

2.5 Statistical analysis

The statistical analysis was carried out using the SAEG computer program, version 9.1. Data were subjected to tests of normality (Lilliefors) and homogeneity of variances (Cochran). The means were compared by Tukey and F tests, at 5% probability. Spearman correlation analysis was performed for agronomic, physicochemical characteristics, and root conservation.

3. RESULTS AND DISCUSSION

Except for root length and mass (pulp) classification, all characteristics related to total yield of tuberous roots, average root weight, cooking characteristics (cooking time [CT] and hardness), biochemical characteristics (dry matter [DM], amylose, amylopectin and starch) and conservation (physiological deterioration of tuberous roots [PPD]) were affected by the harvest time. There was an effect of the interaction of cassava leaf canopy and harvest time only for contents of root moisture.

In addition to the cultivation cycle, the harvest time factor in this study also considered different conditions of water availability in the environment and the plant's physiological condition when the roots were harvested. The eight-month plant was harvested in a period of intense drought and natural abscission of leaves, determining the plant's physiological dormancy. When the roots were harvested at 12 months, higher precipitation rates induced the growth vigor of shoots and roots. The cycle duration and the plant's physiological stage at the time of harvest of the roots were determining factors for the definition of the characteristics assessed.

Restrictive effects of the pruning factor occurred on two biochemical features (DM and starch), on PPD and cooked mass classification, and the absence of interaction between this factor and the harvest time was mainly associated with the pruning-harvest interval which was very. This condition hindered the translocation of the root reserves to the shoots, restricting the magnitude of the effect of pruning on the quantitative aspects of mass accumulation and growth [6].

Suppression of "source" organs by pruning and defoliation at 30 days before harvest did not affect total root yields (varying from 11.00 to 12.05 t ha^{-1}) and the individual morphological characteristics of the root, such as length, (varying from 36.43 to 38.76 cm), and average mass content (values between 0.199 to 0.235 kg) when compared with unpruned cassava plants (Table 1). Partial removal of young leaves during a two-year cycle of the culture, performed every 15 days, did not affect the production of roots in cassava crops grown in Congo [13].

In the present study, nonexistent effects of pruning on the roots size was associated with the fact that this practice was applied after the stage of differentiation and growth of fibrous roots [14]. As a consequence, in the present study, the root morphology was not a factor of interference in the PPD analysis. According to Zainuddin et al. (2018) [5], conclusive analyses of studies on postharvest deterioration of cassava roots can be limited by factors related to the number and individual morphology of sampled roots.

Table 1: Tuberous root yields (TRY), average root length (RL), average root mass (ARM), dry matter (DM), moisture (M), postharvest physiological deterioration (PPD), starch content (S), amylose (AML), amylopectin (AMP), root peeling efficiency (RPE), cooking time (CT), hardness (H) and cooked root mass classification (MC) as a result of management practices and harvest times of sweet cassava, variety Milagrosa. Vitória da Conquista, BA, 2023.

Treatment	TRY (t ha^{-1})	RL (cm)	ARM (kg)	DM	M		PPD
				(%)			
					8 Months	12Months	
Control	12.05 a	36.43	0.404 a	25.55a	66.77 Aa	68.23 Ab	22.14 a
Defoliation	11.88 a	38.76	0.447 a	24.76b	64.83 Ba	71.48 Aa	10.72 ab
Pruning	11.00 a	36.56	0.416 a	24.95b	65.62 Ba	72.21 Aa	7.62 b
CV (%) T	16.68	8.11	8.82	1.48	1.94		66,94
CV (%) HT	-	-	-	-	1,55		

Treatment	S	AML	AMP	RPE		CT	H	MC[1]
		(%)				(min)	(N)	
				8Months	12Months			
Control	20.90 a	18.19	81.81	Easy	Moderate	18.88	155.09 a	8.13 a
Defoliation	20.11 b	18.94	81.06	Easy	Moderate	22.75	150.98 a	5.88 b
Pruning	20.30 b	16.93	83.07	Easy	Moderate	18.88	152.51 a	6.13 b
CV (%) T	1.82	11.04	2.43	-	-	25.57	10.22	18.59

Means followed by same lowercase in columns and uppercase in rows do not differ from each other by the Tukey's test and F-test at 5% probability.
T: treatment (pruning/defoliation/control); HT: harvest times.
[1] Score scale between 4 (very lumpy, not plastic and sticky pulp) to 10 (no lumps, plastic and non-sticky pulp) for classification of the quality of boiled sweet cassava [10].

Pruning of the leaf canopy reduced postharvest deterioration of cassava roots (7.62 %) when compared with unpruned plants (22.14 %) (Table 2). Pruning is a management practice that, for constituting a mechanical injury, triggers activation of the plant's defense mechanisms. This process involves several enzymes of oxidative metabolism, among them catalase, peroxidases and the phenylalanine ammonia-lyase, which delay the PPD of the roots [15]. Pruning-induced biochemical alterations in the root composition, such as an increased sugars/starch ratio, are signs that limit oxidation of the metabolites and result in an accumulation of phenolic compounds such as scopoletin in the roots' vascular tissues [6].

When artificial defoliation was performed, maintaining the branches of cassava plants, an intermediate effect of root deterioration (10.72 %) was observed between the treatments of this study, as it is a milder procedure than total removal of the plant's foliage. The intensity of restriction of the shoots' vegetative vigor is related to the quantitative proportional effects of the roots' susceptibility to PPD [14].

For unpruned plants, higher DM and starch contents were observed in the roots (25.55 and 20.90 %, respectively) when compared with drastically pruned plants (24.76 and 20.11%, respectively), or had their leaves removed (24.95 and 20.30%, respectively) (Table 1). The reduced DM and starch contents in the roots of pruned and defoliated plants at 30 days before harvest were associated with the beginning of the starch-to-sucrose metabolization process for transportation and reconstitution of the aerial parts of the plant [16]. The decreased starch contents in the roots of pruned plants ten days before harvest were associated with activation of alpha-amylase 3 enzyme present in cell plastids, this being the key enzyme of this process [17].

The content of amylose (18.19, 16.93 and 18.94 %) and amylopectin (81.81, 83.07 and 81.06%) for the control, pruning and defoliation, respectively, remained constant when the practice of pruning of sweet cassava plants was analyzed (Table 2). The pruning-harvest interval (30 days) adopted in the present study induced the homogeneity of amylose and amylopectin values due to enhanced root starch hydrolysis, resulting in a breakdown of the amylose and amylopectin fraction in a similar way [18].

Table 2: Tuberous roots yield (TRY), average root length (RL), average root mass (ARM), dry matter content (DM), postharvest physiological deterioration (PPD), starch content (S), amylose (AML), amylopectin (AMP), root peeling efficiency (RPE), cooking time, hardness (H) and cooked mass classification (MC), as a result of the harvest times of sweet cassava, variety Milagrosa. Vitória da Conquista, BA, 2023.

Harvest time	**TRY** ($t\ ha^{-1}$)	**RL** (cm)	**ARM** (kg)	**DM**	**PPD** (%)	**S**
8 Months	10.12 a	36.93 a	0.371 b	25.65 a	20.00 a	21.00 a
12 Months	13.18 b	37.57 a	0.474 a	24.53 b	6.98 b	19.87 b
CV (%) HT	19.98	12.18	16.99	4.09	-	5,02

Harvest time	**AML** (%)	**AMP** (%)	**RPE**	**CT** (min)	**H** (N)	**MC**[1]
8 Months	16.50 b	83.50 a	Easy	15.17 b	142.15 b	6.92 a
12 Months	19.53 a	80.47 b	Moderate	25.17 a	163.58 a	6.50 a
CV (%) HT	10.32	2.27	-	34.19	12.21	22.84

Means followed by same letter in columns do not differ from each other ty the F-test at 5% probability.
HT: harvest times.
[1] Score scale between 4 (very lumpy, non-plastic and sticky mass) to 10 (not lumpy, plastic and non-sticky mass) [10].

The plant shoot management did not affect peeling efficiency, cooking time (CT) (18.88, 18.88 and 22.75 min) and hardness of roots (155.09, 152.51 and 150.91 N, respectively) (Table 2). The main factors that affect the culinary attributes, especially ease of peeling, are varieties and temperature at the harvest time and the peel thickness [19]. Despite evidences in many sweet cassava varieties that CT is high when plants are pruned [20], in the present study there was no difference between the control and the pruning treatment.

For the control, the root mass classification was higher when compared with the treatments with pruning and defoliation, exhibiting values of 8.13, 6.13 and 5.88, respectively (Table 1), almost reaching the desirable quality for cooked root pulp. The fiber content in roots is a factor that keeps an inverse relationship with the period between pruning and harvest, that is, the lowest vegetative vigor achieved with a shorter pruning-harvest interval results in higher fiber content [21]. Plant pruning or defoliation results in a higher lignification of the vascular structure of tuberous roots, increasing the fiber contents, which results in a “lumpy mass” and poorer cooked mass quality.

The pruning management only affected the moisture content in the cassava roots harvested at 12 months after planting, with higher contents in the roots of pruned plants (71.42%) and defoliated plants (72.21%) compared with the control (68.23%) (Table 1). The moisture content in roots is directly associated with the climate conditions and the physiological stage of the plant growth. At eight months after planting, due to the plant physiological dormancy, natural foliar abscission and restriction of vegetative vigor, there was no impact of the plant shoot management in relation to the control. At 12 months after planting (December), the increased water availability and temperature (Figure 1) favored the vegetative vigor of the shoots. The pruning and defoliation management restricted the water flux from the roots to the shoots, increasing the root moisture when compared with the control.

Higher yields and average mass (13.18 tha^{-1}, 0.474, respectively), were found in tuberous roots harvested after 12 months of planting than those harvested after eight months (10.12 tha^{-1}, 0.371, respectively) (Table 2). The extended growth cycle resulted in higher yields due to the greater accumulation of photoassimilates in the roots.

The average root length (36.93, 37.57 cm at 8 and 12 months after planting, respectively) remained constant for both cultivation periods assessed (Table 2), considering that this characteristic is defined at 150 days after planting, with no change in length, and growth is converted into increased root diameter and mass values [22].

DM, starch and amylopectin contents were higher in the roots harvested at eight months after planting (25.65, 21.0 and 83.50 %) (in August) than those harvested at 12-month maturity (in December) (24.53, 19.80 and 80.47 %, respectively) (Table 2). At eight-month maturity, physiological dormancy of cassava plants was induced, characterized by a decline in the metabolic activity and growth, leaf abscission, resulting in greater reserve accumulation in roots. In December, there was mobilization of the root reserves to constitute the shoot structures, mainly leaves, reducing the starch contents in the roots.

The amylose content was lower in the eight-month cycle (16.50 %) than in the roots harvested at 12 months after planting (19.53 %) (Table 2). The lower amylose content was associated with the greater activity of branching enzymes, also justifying the high amylopectin content at the end of the tuberization process, called physiological dormancy period [23]. Advanced crop maturation and in the postharvest conservation period is a factor of reduction of amylose contents.

The 12-month cycle was associated with production of roots with higher amylose contents, thus being an alternative for use in the industry. The higher amylose concentration makes starch less susceptible to chemical and physical changes, resulting in a food with low digestibility, with possible application in foods for diabetics and fried products since it reduces absorption of fat [24]. Starch with high concentration of amylose is a suitable feedstock for the industry of candies, adhesives and paper, reducing costs of pre-industrialization processes and eliminating the disposal of harmful wastes in the environment [4].

Better peeling efficiency, CT and hardness were found for the roots harvested at 8 months after planting (easy peeling, 15.17 minutes, 142.15 N) compared to the 12-month cycle (moderate peeling, 25.17 minutes, 163.58N) (Table 2). Early-cycle roots determine easier peeling and lower CT when compared with roots harvested later [10].

According to [19], there are evidences that the thicker peel of cassava roots makes peeling easier, establishing a negative relationship between the starch content and peel thickness. Thus, maximization of the starch content was associated with peel reduction. In the present study, lower starch contents and better peeling efficiency were observed for the roots harvested eight months after planting than after 12 months (Table 2).

In prolonged cultivation cycles, fiber contents in roots increase as a result of lignin accumulation in the interfibrillar spaces of the cell wall, resulting in less elasticity and higher tissue hardness. During the physiological dormancy period, the organoleptic quality of roots is maximized [25]. In the present study, the higher starch and amylopectin levels and shorter CT were associated with harvesting during the dormancy period.

The higher rainfall rates during the harvest carried out at 12 months after planting (December) favored the vegetative growth, reducing the root DM and starch, increasing CT and fiber contents in the roots. Cassava roots harvested with higher moisture contents and lower starch contents have high CT [25].

It can be seen that the cassava roots harvested at eight and 12 months after planting did not show difference in the classification of cooked mass, with values between 6.92 and 6.50, respectively (Table 3), indicating high root quality, i.e., non-lumpy, plastic and non-sticky cooked mass [26].

Correlations between the DM of roots and all biochemical and culinary characteristics, except for mass classification, were observed (Table 3). As starch is mostly the main component of the root dry matter (73.4 to 84.9%), a positive correlation was established between these two characteristics (r = 0.45).

Variations observed in starch content when determined by laboratory analyses (direct method) compared with that determined with hydrostatic weighing (indirect method) are explained by the heterogeneous mass and carbohydrates distribution in the root tissues [19]. Therefore, some correlations involving carbohydrates in studies (starch, amylose and amylopectin), must be analyzed with caution.

Table 3: Spearman correlation between starch content (S), dry matter (DM), amylose and amylopectin (AML:AMP), cooking time (CT), mass classification (MC), moisture content (M), hardness (H) and postharvest physiological deterioration (PPD) for sweet cassava, variety Milagrosa. Vitória da Conquista, BA, 2023.

Characteristics	**S**	**AML:AMP**	**CT**	**MC**	**M**	**H**	**PPD**
DM	0.45*	-0.49*	-0.37*	0.21	-0.58*	-0.41*	0.53*
S		-0.24	-0.32	-0.01	-0.27	-0.24	0.09
AML:AMP			0.32	0.01	0.49*	0.32	-0.23
CT				-0.02	0.49*	0.04	-0.48*
MC					-0.24	0.06	0.38*
M						0.18	-0.65*
H							-0.28

*significant at 5 % probability by T-test.

There was a positive correlation between DM and PPD (r = 0.53) (Table 3), a fact that hinders the advancement of conventional breeding when limitation of PPD processes is aimed [27]. In the present study, the pruning management and planting times did not affect this correlation, remaining positive. Similar to the present study, Nuwamanya et al. (2019) [7] found, in Uganda, for five commercial cassava varieties that were subjected to preharvest pruning the occurrence of a positive correlation between DM and PPD. The greater substrate availability intensifies the PPD-related oxidative processes. Studies have reported that factors that restrict starch metabolization lead to a delay in PPD [28].

Negative correlations between DM and the amilose:amilopectina ratio (AML: AMP) (r = 0.49), CT (r = 0.37) and H (r = 0.41) characteristics established that the root culinary quality was related to a DM increase (Table 4). However, the negative correlation between DM and M (r = 0.58), which occurs simultaneously with the positive correlation between DM and PPD, indicated that the DM increase was associated with a higher susceptibility to PPD. The reduced moisture and the increased DM in the roots are interdependent factors and are associated with a higher susceptibility of the roots to degenerative oxidative reactions, resulting in PPD.

The moisture content is an important trait with direct influence on postharvest root conservation, given that the higher the water content in roots, the lower is the PPD degree. Low moisture contents in roots enhance the oxidative processes, such as the accumulation of hydrogen peroxide and lipid peroxidation, which accelerates PPD [29].

The water content showed a positive correlation with CT (r = 0.49) and the amylose and amylopectin content (r = 0.49) (Table 3). The increase of moisture content favors starch degradation into smaller fractions, such as sugars, and they are translocated through the xylem to maintain and form new vegetative structures of the plant [18]. Therefore, the DM in the roots is reduced, and the agronomic and culinary attributes are negatively affected. Cassava roots with higher moisture contents and lower DM levels (higher AML/AMP) require more CT, as observed by [25].

CT and MC determine the culinary quality of cassava roots, maintaining negative (r = 0.48) and positive (r = 0.38) correlations, respectively, with PPD (Table 3), stressing once again that the positive aspects of root quality (shorter CT and higher PPD) were associated with increased PPD. The negative correlation between PPD and CT was associated with the restriction of phenolic compounds for PPD, which deviated to form lignin, induced by mechanical injuries [30].

4. CONCLUSIONS

1. The 12-month crop cycle is associated with higher root yields and conservation time, but the highest quality attributes for consumption of cassava roots are found in roots harvested earlier (8 months).
2. Pruning performed at 30 days before harvest is a practice that reduces physiological deterioration of tuberous roots compared with unpruned plants.
3. Management of the aerial part of the plant by drastic pruning or defoliation, carried out at 30 days before harvesting, does not affect the root yields and cooking time.

5. BIBLIOGRAPHIC REFERENCES

1. Instituto Brasileiro de Geografia e Estatística (IBGE). Sistema IBGE de Recuperação Automática – SIDRA [Internet]; 2021 [cited 2023 Apr 08]. Available from: https://www.sidra.ibge.gov.br/bda/prevsaf
2. Mtunguja MK, Beckles DM, Laswai HS, Ndunguru JC, Sinha NJ. Opportunities to commercialize cassava production for poverty alleviation and improved food security in Tanzania. African J Food Sci. 2019;19(1):13928-46. doi: 10.18697/ajfand.84.BLFB1037
3. Salcedo A, Siritunga D. Insights into the physiological, biochemical and molecular basis of postharvest deterioration in cassava (*Manihot esculenta*) roots. American J Exp Agric. 2011;1(4):414-31. doi: 10.9734/AJEA/2011/784
4. Uchechukwu-Agua AD, Caleb OJ, Opara UL. Postharvest handling and storage of fresh cassava root and products: a review. Food Bioprocess Technol. 2015;8(4):729-48. doi: 10.1007/s11947-015-1478-z
5. Zainuddin IM, Fathoni A, Sudarmonowati E, Beeching JR, Gruissem W, Vanderschuren H. Cassava post-harvest physiological deterioration: From triggers to symptoms. Postharvest Biol Tec. 2018;142(1):115-23. doi: 10.1016/j.postharvbio.2017.09.004
6. Van Oirschot QEA, O´Brien GM, Dufour D, El-Sharkawy MA, Mesa E. The effect of pre-harvest pruning of cassava upon root deterioration and quality characteristics. J Sci Food Agric. 2000;80(13):1866-187.
7. Nuwamanya E, Acheng S, Vuzi P, Muyinza H, Matovu M, Atwijukire E, et al. Effectiveness of pruning and waxing in reducing postharvest physiological deterioration in Uganda local cassava varieties. African Crop Sci J. 2019;27(2):237-51. doi: 10.4314/acsj.v27i2.9.
8. Grossman J, Freitas AC. Determinação do teor de matéria seca pelo peso específico em mandioca. Rev Ciênc Agron. 1950;14(160/162):75-80.
9. Conceição AJ. A Mandioca. São Paulo: Ed Nobel; 1983.
10. Pereira AS, Lorenzi JO, Valle T. Avaliação do tempo de cozimento e padrão de massa cozida de mandioca de mesa. Rev Bras Mandioca. 1985;4(1):27-32.
11. International Organization for Standardization (ISO). Norme internationale: Riz-détermination de lateneurem amylose. Switzeland: ISO; 1987. (ISO 66470).
12. Wheatley C, Lozano C, Gómez G. Deterioracion postcosecha de raices de yuca. In: Domiguez CE, editor. Yuca: investigacion produccion e utilizacion. Colômbia: Cali, CIAT; 1982. p. 493-510.
13. Munyahali W, Pyers P, Swennen R, Walangululu J, Vanlauwe B, Merckx R. Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. Field Crops Res. 2017;214(1):194-201. doi: 10.1016/j.fcr.2017.09.018
14. Ecco M, Costa ACT, Duarte Júnior JB, Borsoi A. Levels and stages of artificial defoliation in the agronomic performance of the cassava crop. Emir J Food Agric. 2019;31(11):818-24. doi: 10.9755/ejfa.2019.v31.i11.2033
15. Saravanan R, Ravi V, Stephen R, Thajudhin S, George J.Post-harvest physiological deterioration of cassava (*Manihot esculenta*) − A review. Indian J Agric Sci. 2016;86(11):1383-90.

16. Amarullah BH, Indradewa D, Yudono P, Dan Sunarminto BH. Effect of source-sink manipulation on yield and related yield components in cassava, *Manihot esculenta* Crantz. Int J Agric Innov Res. 2016;6(2):69-76.
17. Chen Y, Huang S, Tang Z, Chen X, Zhang Z. Structural changes of cassava starch granules hydrolyzed by a mixture of - amylase and glucoamylase. Carbohydr Polym. 2011;85(1):272-5. doi: 10.1016/j.carbpol.2011.01.047
18. Zeeman SC, Kossmann J, Smith AM. Starch: Its metabolism, evolution, and biotechnological modification in plants. Annu Rev Plant Biol. 2010;61(1):209-34. doi: 10.1146/annurev-arplant-042809-112301
19. Pérez JC, Lenis JI, Calle F, Morante N, Sánchez T, Debouck D, et al. Genetic variability of root peel thickness and its influence in extractable starch from cassava (*Manihot esculenta* Crantz) roots. Plant breed. 2011;1(30):688-93. doi: 10.1111/j.1439-0523.2011.01873.x
20. Oliveira SP, Viana AES, Matsumoto SN, Cardoso Júnior NS, Sediyama T, São José AR. Efeito da poda e de épocas de colheita sobre características agronômicas da mandioca agronômicas da mandioca. Acta Sci Agron. 2010;32(1):99-108. doi: 10.4025/actasciagron.v32i1.922
21. Moreira GLP, Prates CJN, Oliveira LM, Viana AES, Cardoso Júnior NS, Figueiredo MP. Composição bromatológica de mandioca (*Manihot esculenta*) em função do intervalo entre podas. Rev Ciênc Agrár. 2017;40(1):144-53. doi: 10.19084/RCA16022
22. Figueiredo PG, Bicudo SJ, Moraes-Dallaqua MA, Tanamati FY, Aguiar EB. Componentes de produção e morfologia de raízes de mandioca sob diferentes preparos do solo. Bragantia. 2014;73(4):357-64. doi: 10.1590/1678-4499.0150
23. Souza Fernandes DS, Santos TPR, Fernandes AM, Leonel M. Harvest time optimization leads to the production of native cassava starches with different properties. Int J Biol Macromol. 2019;(1):710-21. doi: 10.1016/j.ijbiomac.2019.03.245
24. Noal DT, Denardin CC. Importância da resposta glicêmica dos alimentos na qualidade de vida. Rev Eletr Farm. 2015;12(1):60-78.
25. Cereda MP, Vilpoux OF. Tecnologias, usos e potencialidades de tuberosas amiláceas latino americanas. São Paulo: Fundação Cargill; 2007.
26. Anjos DN, Viana AES, Cardoso AD, Matsumoto SN. Características culinárias e teor de amido de variedades de mandioca avaliadas em dois períodos na região sudoeste da Bahia. Enciclopédia Biosfera J. 2014;10(18):785-93.
27. Tumuhimbise R, Melis R, Shanahan P. Genetic variation in cassava for postharvest physiological deterioration. Arch Agron Soil Sci. 2015;61(9):1333-42. doi: 10.1080/03650340.2014.995641
28. Hu W, Tie W, Ou W, Yan Y, Kong H, Zuo J, et al. Crosstalk between calcium and melatonin affects postharvest physiological deterioration and quality loss in cassava. Postharvest Biol Tec. 2018;140(1):42-9.
29. Chakraborty U, Pradhan B. Oxidative stress in five wheat varieties (*Triticum aestivum* L.) exposed to water stress and study of their antioxidant enzyme defense system, water stress responsive metabolites and H_2O_2 accumulation. Brazil J Plant Physiol. 2012;24(2):117-30. doi: 10.1590/S1677-04202012000200005
30. Freire CS, Simões AN, Simões N, Paes A, Júnior GB, Ribeiro M, et al. Activity of oxidative enzymes involved in the browning of minimally processed sweet cassava (*Manihot esculenta* Crantz). Aust J Crop Sci. 2014;9(4):296-302.